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COPPER ORES

BY

ROBERT ALLEN, M.A. (CANTAB.), B.Sc. (LOND.), M.INST.M.M.

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IMPERIAL INSTITUTE

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THE Imperial Institute is a centre for the exhibition and investigation of minerals with a view to their commercial development and for the supply of information respecting the sources, composition and value of minerals of all kinds.

The Imperial Institute is provided with Research Laboratories for the investigation, analysis and assay of minerals, and undertakes reports on the composition and value of minerals, for the information of Governments and producing companies and firms, in communication with the principal users in the United Kingdom and elsewhere in the Empire.

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A special staff is engaged in the collection, critical revision and arrangement of all important information respecting supplies of minerals especially within the Empire, new methods of usage and other commercial developments.

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THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilization of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

IMPERIAL INSTITUTE,
LONDON, S.W.7,
July 1920.

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COPPER ORES

CHAPTER I

COPPER ORES: THEIR OCCURRENCE, CHARACTERS AND USES

INTRODUCTION

THE use of copper possibly dates back about 8,000 years. At the present time copper holds the second place of importance as regards value amongst the base metals, iron ranking first. It is used in various commercial forms and in numerous alloys. In most cases there are no substitutes, and the demand for it is ever increasing.

In the year 1800 the world's production of copper was about 10,000 tons, whilst in 1918 it was 1,370,000 tons. In the nineteenth century about 19,000,000 tons were consumed mainly in railways and other applications of steam power, and in the sheathing of wooden ships with Muntz metal, and, later on, in the electrical industries, which in present times normally absorb about two-thirds of the total production.

During the Great War it was variously estimated that from 65 to 80 % of the world's copper output was used for military purposes, but no exact data are available: production was then greatly pressed forward, every available source of copper being utilized.

At the time of the signing of the Armistice stocks of copper were several times the normal amount. These stocks had to be disposed of gradually. There was consequently a sharp fall in price, which was followed by the forced curtailment of mining operations. This largely accounts for the present great depression in the copper industry. A revival may be looked for as soon as industrial and exchange conditions have

been stabilized as, in Europe especially, there are large undertakings under consideration, mainly in the electrical industries, for extension of power plant, the electrification of railways, the expansion of telephone systems and the development of hydro-electric power. Much copper will be wanted for all these as well as to supply domestic wants generally. If the total output of copper for the United States for the five years 1915 to 1919 be taken as 100, then the next important total outputs for the same period were: British countries, 13; Japan, 12; Chile, 10; Mexico, 6; Peru, 5. In spite of this superiority, American producing companies, with an eye to the future, are largely increasing their interests in foreign countries, especially Chile, Peru, Mexico and Canada.

Growth of the Copper Industry

At the beginning of the last century almost the whole of the world's output came from the British Isles, ore being mined in Cornwall, Devon, Anglesey, and Ireland principally, and smelted at Neath or Swansea in South Wales. Brown and Turnbull [1] estimated that the United Kingdom produced in the century a total of 864,660 long tons.

Early in the last century the "Associated Copper Smelters" was formed at Swansea, and was in a position to control the copper market, keeping the buying prices of ores and regulus low and the selling prices of finished copper high. Chiefly owing to the extended use of steam machinery for hauling and pumping in the Cornish mines, output was much increased towards 1830, and during the next 10 years reached a maximum of importance and remained practically constant for the next 30 years; after that it declined to an almost negligible amount.

The diagram on page 37 graphically shows the outputs of various countries during the nineteenth century. At about 1835, Chile began to export copper ores to the United Kingdom. In 1845, the United States produced 100 tons of copper.

Mining companies abroad eventually started the treatment of their own ores, and matte or metal was largely exported in place of raw ore. In 1842 Lambert erected the first reverberatory furnace in Chile, and in 1857 the first blast furnace. Chile became the world's chief producer in 1850, overtaking

Great Britain. She now began exporting copper direct to the continent of Europe, instead of through the medium of the Welsh smelters.

Spain, Portugal and the United States became important producers at about the same time, their yields being nearly equal for about 40 years. In the last decade of the century the United States definitely became chief producer with an output of one-third that of the world.

Australia began mining copper ore in 1845 in South Australia; New South Wales, Queensland and Tasmania contributing later. The Australian output declined after 1900, as the supply of rich surface ores was lessened [2].

The enormous growth of the United States as a copper-producing country, compared with the rest of the world, is shown on the diagrams on pages 37 and 40

Ore Minerals of Copper

Copper forms compounds with 36 other elements, and there are about 240 copper-bearing minerals. Of these only a few are of economic importance.

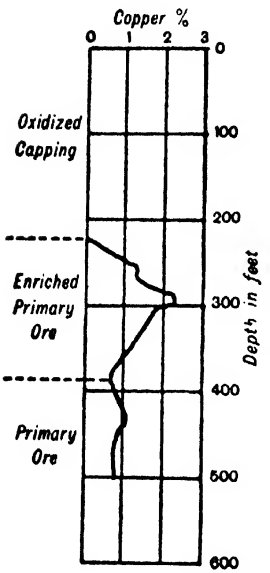
The following table gives the principal minerals of economic value [3/p. 569]:

Class of mineral.	Name.	Formula.	Copper %.	Specific gravity.	Whether primary or secondary.[1]
Sulphide . .	Chalcopyrite	$Cu_2S.Fe_2S_3$	34·6	4·1 to 4·3	P. S.
,, . .	Bornite	$3Cu_2S.Fe_2S_3$	55·5	4·9 to 5·4	P. S.
,, . .	Covellite	CuS	66·5	4·6	S.
,, . .	Chalcocite	Cu_2S	79·8	5·5 to 5·8	S. P.
Sulph-arsenide	Enargite	$3Cu_2S.As_2S_5$	48·3	4·45	P.
,,	Tennantite	$4Cu_2S.As_2S_3$	57·5	4·4 to 5·1	P.
Sulph-antimonide .	Tetrahedrite	$3Cu_2S.Sb_2S_3$	52·1	4·4 to 5·1	P.
Oxide . .	Melaconite or tenorite	CuO	79·8	5·8 to 6·25	S.
,, . .	Cuprite	Cu_2O	88·8	5·85 to 6·12	S.
Sulphate .	Chalcanthite	$CuSo_4.5H_2O$	25·4	2·1 : to 2·30	S.
,, . .	Brochantite	$CuSo_4.3Cu(OH)_2$	56·0	3·9	S.
Carbonate .	Malachite	$CuCo_3.Cu(OH)_2$	57·3	3·9 to 4·03	S.
,, .	Azurite	$2CuCo_3.Cu(OH)_2$	55·1	3·77 to 3·83	S.
Silicate . .	Chrysocolla	$CuSiO_3.2H_2O$	36·0	2 to 2·24	S.
Oxychloride .	Atacamite	$CuCl_2.3Cu(OH)_2$	59·4	3·75	S.
Native metal .	Native copper	Cu	100	8·9	S. (P?)

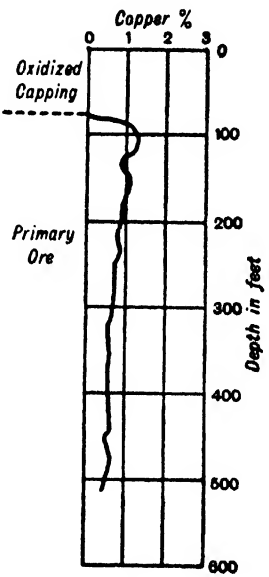
[1] *See* p. 4.

Enrichment of Copper Ores

Cupriferous pyrite, not included above, and chalcopyrite are the minerals most commonly found. These and other primary, or original, minerals, when existing in the " vadose " zone or belt of weathering, are converted by oxygen and cir-



Curve showing Enriched Ore Overlying Primary



Curve showing Primary Ore

culating water into sulphates. These sulphates are carried down leaving a leached zone behind, and usually are gradually concentrated in a zone of oxide enrichment below, which is often profitable enough to mine. Below this zone the sulphate, when in siliceous rocks, coming in contact with a reducing agent, such as a lean sulphide, forms with it a secondary mineral richer in copper. Thus a second zone, with great concentration of copper, may be formed at or near ground water-level.

This is known as *secondary enrichment*. The common minerals of this zone are covellite and chalcocite, these being formed from primary pyrite or chalcopyrite in the order named. This was proved experimentally by Zies, Allen and Merwin [4]. This zone or second horizon is one of high value usually. Below it are the primary minerals of lower grade, chalcopyrite and cupriferous pyrite, which form the *primary* or *lean zone*. Below this primary zone is barren pyrite.

It is a sure indication of secondary enrichment if chalcocite or covellite forms a sooty black coating on other sulphides, partly or wholly replacing them. The breaking-open of a specimen often exhibits a core of original sulphide. Veinlets of secondary sulphides are often found cutting through the original sulphides.

The plotting of the assays of cores, resulting from drilling, against depths, shows where copper deposits are enriched, the amount of a peak on the curve indicating the amount of enrichment. The curves of primary deposits are distinguished from secondary ones by their greater uniformity. The curves on the opposite page exhibit this [5/p. 408].

Most of the copper deposits of the world that are being worked have been enriched.

The greatest dimension of secondary ore-shoots is generally horizontal, whilst with primary ore-shoots the reverse is the rule [6/p. 176].

In regions of high latitude, such as Northern Canada and Northern Europe, which have been subjected to glacial action, and where temperatures are low, little or no oxidation has taken place since the glacial period, and the ore minerals are primary from the surface down, being mostly chalcopyrite and cupriferous pyrite. Nearer the equator in non-glaciated regions, especially where the temperature is high, oxidation has taken place and the ore minerals usually are secondary at and near the surface. The amount of oxidation depends upon the topography of the ground, the porosity of the rock, the rainfall, temperature and other factors. When the rainfall is high, the ground water-level may not be over 100 ft. deep and the oxidation zone is comparatively shallow; when low or

very deficient, especially in very faulted ground, the wate level may be found at great depths, the oxidation zone beir correspondingly deep. In the Dulcinea mine, N.E. of Copiap Chile, for example, it is at places 1,700 ft. deep. The Przibra mines in Czechoslovakia are dry at 2,400 ft. depth.

In some places, owing to the lowering of the water-leve secondary sulphide ores originally formed below it are no above, it, whilst in others, owing to a rising of water-leve oxidized ores originally formed above it are now below it.

In countries of little or no rainfall, such as the desert region of Chile, deposits of soluble or semi-soluble minerals of coppe are formed by the extremely slow weathering of lodes tha takes place. These oxidized minerals are usually brochantite atacamite and chalcanthite, and are now important source of copper. The formation of atacamite is only possible i regions of extreme aridity.

The leached zones of solid pyritic lodes, mainly compose of the oxides of iron, brown hæmatite and limonite, are calle pyritic gossans, and are often the cappings of cupriferou lodes. Especially is this likely to be the case when th gossans contain gold and silver, over 20 % barytes, over 10 % silica and less than 10 % manganese dioxide ; when scoriaceou in appearance, especially at the surface ; and when the lode i in igneous rocks or in metamorphic schists. These points ar of importance when prospecting for copper.

When leaching has been incomplete carbonates and oxide of copper may be left behind in the gossan.

Pyritic gossans are best developed in tropical and temperat countries, where there is insufficient rainfall to remove th capping after oxidation, and the water-level is a good depth below the surface.

Gossans of copper-bearing lodes, which may contain copper, might possibly be confused with gossans of pure iron ore deposits consisting of limonite derived from carbonate of iron (siderite), but these iron gossans usually are more compact in appearance, do not carry gold and silver, contain very small amounts of silica, and over 2 % manganese dioxide. They

are found in sedimentary rocks chiefly of a calcareous nature [7].

In some cases in the Urals, in the last few years, pyritic copper lodes have been discovered after the cappings had been removed for the purpose of iron-smelting.

If oxidizing reactions occur in open-textured tuffs or contact lime-silicates, enrichment often occurs with formation of chrysocolla instead of chalcocite. Blue and green carbonates and cuprite are characteristic products in the presence of limestone.

In arid regions, where the ore below the outcrop of a lode has been explored, it has often been found that pyrite oxidizes to a massive brown material, whilst chalcopyrite becomes converted into seamlets and patches of soft, bright-red hæmatite.

Classes of Copper Deposits

The majority of copper deposits, which are mainly associated with igneous rocks, may be classed under the following heads, although some amount of overlapping may occasionally occur:

1. *Magmatic Deposits.*—These are primary segregations or crystallizations from magma (or material from the interior of the earth, originally molten) of copper-bearing sulphides, chiefly chalcopyrite or lean cupriferous pyrite. The containing igneous rock is usually basic and the deposits are of low grade. These deposits are rare and are seldom exposed. The chalcopyrite may be associated with nickel in the mineral pentlandite and with pyrrhotite.

Examples: At Sudbury (Ontario), Namaqualand (South Africa), Tuscany and Liguria (North Italy).

2. *Vein Deposits.*—These are the result of the filling of open fissures (*fissure veins*) or of replacement of the wall rocks along narrow cracks, forming workable ore-bodies (*replacement veins*). The fissures or cracks generally cut through the bedding of the country rock. When passing through a homogeneous rock, such as a granite or a sandstone, a fissure is usually well-defined, but in shaly or schistose rocks it may appear as a number of smaller fissures.

Replacement veins vary in width with the solubility of the

wall rock, an enriched zone being often formed, for example, in limestone. The two processes of vein formation may have been at work in the same vein.

Examples: At Butte (Montana); Bingham (Utah); Old Dominion (Arizona).

3. *Pyritic Lenses.*—These are lenticular or pod-shaped deposits of pyrite or pyrrhotite, with chalcopyrite, usually in crystalline schists or slates, lying parallel with the foliation. Pyritic lenses were formerly the main source of the world's supply of copper.

Examples: At Rio Tinto, Tharsis, San Domingo (Spain); Mt. Lyell (Tasmania); Kyshtim (Russia); Sulitelma (Norway); Bodenmais (Bavaria); Latouche Island (Alaska); Quebec (Canada); Ducktown (Tennessee); United Verde, United Verde Extension (Arizona); Jerome District (Arizona); Shasta (California). Some of the largest ore-bodies known occur at Rio Tinto.

4. *Contact Metamorphic Deposits.*—These are masses, generally irregular or tabular in form, of copper-bearing sulphides, formed along the contact zones between intrusive rocks and sedimentary rocks, or in the latter rocks in the near neighbourhood of the intrusive rock. They are characterized by the unique association of oxides of iron with sulphides, and are usually confined to rocks that possess strong precipitative action, such as limestone. Few of the contact deposits of the Old World are of commercial importance, but in North America there are some which are great producers. Few are mined to any appreciable depth. The ores of these deposits, unless of smelting grade, are difficult to treat metallurgically on account of the densities of their gangue minerals, especially when derived from garnet zones.

Examples: At Petchikan District, Hetta Inlet District (Alaska); Whitehorse (Yukon); Boundary District (British Columbia); Ely (Nevada); Bingham (Utah); Silverbell, Morenci, Twin Buttes, Clifton, Bisbee, Ajo, Copper Queen (Arizona); Santa Rita (New Mexico); San José, Velardeña, Cananea, Matehuala (Mexico).

5. *Native Copper Deposits.*—In these the native metal is found in various forms, such as large branching masses, nodules,

sheets or minute scales, and usually in bedded veins of conglomerates or associated amygdaloidal basalts.

Examples of major importance: At Keweenaw Point (Michigan); Corocoro (Bolivia).

Examples of minor importance: At Bay of Fundy (Nova Scotia); White River Region (Alaska); Coppermine River and Bathurst Inlet (N.W. Territories); Oregon; Papua; Brazil; Transbaikal; Norway; Germany.

6. *Bedded Deposits or Seams.*—These are impregnations of sedimentary rocks with disseminated sulphides or their oxidized products, which are often deposited on organic remains. Compared with the thickness they are usually of large horizontal dimensions, and are of low grade.

Examples: At Mansfeld (Germany); Boleo (Lower California); Red Sandstone Beds (New Mexico, Texas etc.); Katanga (?) (Belgian Congo); Khirgiz Steppes (S.W. Asia); Perm (Russia).

7. *Disseminated Chalcocite Enrichments or Impregnations.*—These are generally known as "porphyry copper blanket deposits" or "porphyries," and are now one of the principal sources of copper. They are of low grade and mainly found in the south-west part of the United States. The primary ore of such deposits is disseminated cupriferous pyrite and chalcopyrite, usually associated with quartz and accompanied with sericitization and silicification of the contained rocks. The zone of enrichment is below an almost completely leached and kaolinized capping, and the metal is deposited below as an extensive sheet or *blanket*, chalcocite completely replacing the pyrite. Below this is primary rock, into which generally it is useless to prolong vertical exploration. The mines are found in fractured or altered porphyry or schist.

Examples: At Inspiration, Miami, Ray, Arizona Hercules, Clifton-Morenci, Ajo, Sacramento Hill, Calumet and Arizona (Arizona); Chino, Burro Mountain (New Mexico); Nacozari (Mexico); Bingham (Utah); Ely (Nevada).

At Ajo and Nacozari primary ore is mined, and at Ajo large bodies of oxidized ore are utilized. Such low-grade material is so profitably mined that all the large porphyry companies include in their reserves ore containing as low as 1 % copper.

8. *Replacement Deposits.*—These are formed by the replacement (or exchange) of the country rock by ore formed by mineralizing solutions. The replaced rock is usually a limestone or other easily-soluble rock, but there are large replacement deposits in quartzites, shales and schists. Next to its solubility, the amount of shattering, brecciation or straining to which the replaced rock has been subjected is of importance for the formation of such deposits. These deposits commonly occur in the vicinity of, although not adjacent to, intrusive rocks, and sometimes are closely related to contact deposits. They are rarely of great depth, and usually the rocks above them give no indication of their presence, so that blind exploration is often justified. Limestones, in the immediate neighbourhood of these deposits, are altered by mineralization and silicification, and often by mineralization by disseminated pyrite.

Examples: At Kennecott (Alaska); Gila Copper Sulphide, Gila Canyon Consolidated, London Arizona, Copper Queen, and Calumet and Arizona at Bisbee (Arizona) [3][5][6][9 to 12].

Copper Production from Different Classes of Deposit

According to an analysis of the world's production of copper [13/2, p. 943] for the year 1910, estimated percentages of the total produced by different classes of deposits are as follow:

	Percentage of total.
Magmatic deposits:	
Nickel-pyrrhotite group, about 1%	10 to 11
Bornite group, 0–5%	
Pyrite group, 0–10%	
Contact deposits, and combined contact- and lode-deposits	25 to 30
Lodes	about 40
Replacement deposits	„ 3
Native copper deposits	„ 12
Bedded deposits:	
Kupers.hiefer, 2·3%	„ 4·3
Other ore-beds, about 2%	
Deposits of other metals in which copper is subsidiary	„ 1

Copper Production from Different Classes of Ore

An analysis made of the world's production of copper for 1909 according to the different ores [13/2, p. 872] gave the estimated percentages of the total as here shown:

Class of ore.	Long tons.	Percentage of total.
Native Copper:		
Michigan (U.S.A.)	101,000	12
Corocoro (Bolivia), etc.	2,000	
Carbonate-Oxide ores . . . about	150,000	15 to 20
Enargite, $\frac{1}{10}$ of Butte production and others	40,000	5
Tetrahedrite and other sulpho-salts	—	1 to 2
Chalcopyrite, Bornite, Chalcocite (One-half of this amount comes from chalcopyrite and cupriferous pyrite)	—	60 to 65
Total production	840,000	—

Minerals associated with Copper in Nature

Copper and silver are very closely related, having many chemical properties in common. Generally all deposits of copper contain some silver. Ratios of silver to copper common in various copper ores are as follow: Lake Superior, native copper, less than 1 : 1000; pyrite deposits, generally not above 1 : 1100; Butte, Montana, 1 : 400; Mansfeld (*kupferschiefer*) 1 : 175.

Gold is often associated with the silver in copper deposits. Tin and copper are found together in Cornwall and in the Herberton district of Queensland, Australia. In some cases the tin ore is separate from the copper ore; in others the two ores may occur in different parts of the same fissure. Copper, nickel and cobalt are found together in nickel-pyrrhotite deposits, and in many lodes and pyrite deposits. Copper and manganese are often associated in the oxide zones of copper lodes of Arizona, and in copper ore-beds at Boleo, Lower California [13/1. p. 1183]. Copper is also frequently found associated with zinc and, in very small quantities, with platinum, palladium, selenium, tellurium, and bismuth, which are separated by electrolytic refining (*see* p. 18). Lead and vanadium are rare associates.

The following gangue minerals are commonly found with copper in copper deposits: Quartz, the commonest; calcite and siderite, abundant in a few; barytes, rhodochrosite, fluorspar, sericite, tourmaline (in some tin-copper and gold-copper veins) [3/p. 569].

Mining of Copper Ores

The mining of most deposits of copper is carried on usually by the same methods employed with ore-bodies of other metals. Of recent years it has been possible to attack immense low-grade deposits such as those of the "porphyries," owing to the development of large-scale systems of mining, of which the most important are the so-called caving systems, and when the deposit is near the surface, to the use of the steam or electric shovel, or digger, for open-cut or stripping work. Shovelling machines and scrapers have been also largely used of late years in underground work. The substitution of electric power for steam for hoisting and for haulage, and other improvements, have generally resulted in great economies.

In the United States, according to B. S. Butler [8/p. 148], the production of copper in the ore mined per man employed per day increased in all mines from 75 lb. in 1912 to 100 in 1916. In Utah in the same period, largely owing to the use of the steam shovel, it increased from 80 to 175 lb. In the Inspiration mines at Miami, Arizona, the production per man in 1917 averaged 350 lb. copper. The output of the United States for the year 1916 was divided according to the average productions per man as follows:

Average production per man per day. lb.	Percentage of total output.
Over 300	22·5
200 to 300	14·5
100 „ 200	16·5
75 „ 100	26·5
50 „ 75	9·5
30 „ 50	5·0
Less than 30	4·0
By-product copper	1·5

Descriptions of some modern copper-mining methods will be found in the following references: [10], [14 to 19].

Tenor of Copper Ores

In late years, owing to large-scale operations and to improvements in mining and metallurgy, it has been possible to work profitably much lower grade ore. In the United States in the period 1907–1916 the average amount of copper recovered

in all copper mines decreased from 43 to 34 lb. per ton, or from 2·15 to 1·7 % [8/p. 147]. For purposes of illustration the results of recent operations of three large American companies are given below :

Company.	Year.	Average ore tonnage per day.	Grade of ore (% Cu).	Recovery, lb. per ton.	Extraction, %.
Utah Copper .	1911	12,750	1·51	21·0	69·5
	1918	33,400	1·23	16·0	65·1
Inspiration Consolidated	1916	14,850	1·55	23·2	74·9
	1918	14,170	1·30	19·8	73·0
Chile Copper . .	1915	2,800	1·71	17·5	66·9
	1918	10,200	1·04	27·3	82·2

Purchasing of Copper Ores

In valuing copper ores for purchase a wet or electrolytic assay is made of a carefully prepared sample, and an amount, usually varying from 0·5 to 1 unit, is deducted to cover an assumed treatment loss, which rarely exceeds 1·3 units per ton.[1] The balance is paid for according to the current market quotation, less a treatment charge per ton of ore for smelting, refining, and treating to bring the copper into marketable shapes. This treatment charge is generally on a sliding scale according to grade, premiums or penalties being made according to the class of the ore, and penalties according to impurities.

Gold if present in amount over 0·05 oz. per ton is generally paid for in full, at a price varying according to the richness of the ore. Silver, if present in amount over about 0·5 oz., is usually paid for on the basis of 95% of the ore content at the current market quotation for bar silver at the time agreed on [*see* 5/p. 1803].

Objectionable Elements in Copper Ores

The elements associated with copper ores, which are as a rule metallurgically very undesirable, include zinc, bismuth, arsenic, antimony, tellurium and selenium.

Zinc is very objectionable in smelting, forming viscous

[1] A unit is one-hundredth of a ton.

slags of high melting point, and, through volatilization, accretions in the stacks and other parts of the smelting plant.

Bismuth is rare, but even small quantities render copper unworkable; as little as 0·02 % makes copper red-short, and 0·05 %, cold-short, but small amounts of antimony tend to neutralize its ill effects. Oxide of bismuth, which is mechanically taken up by copper, acts similarly, but its bad effects are reduced when cuprous oxide is present. Bismuth is eliminated by electrolytic refining.

Arsenic, antimony, tellurium, and selenium all reduce the electrical conductivity of copper. Over 1 % arsenic or antimony produces red-shortness; smaller amounts of tellurium and selenium also produce red-shortness, whilst arsenic or antimony in small amount improves the mechanical properties of copper. These elements can also be eliminated by electrolytic refining.

Silica, when in large amount in an ore, which has to be smelted direct, is undesirable, as smelting capacity is reduced, and extra basic flux is required [3/p. 569] [20].

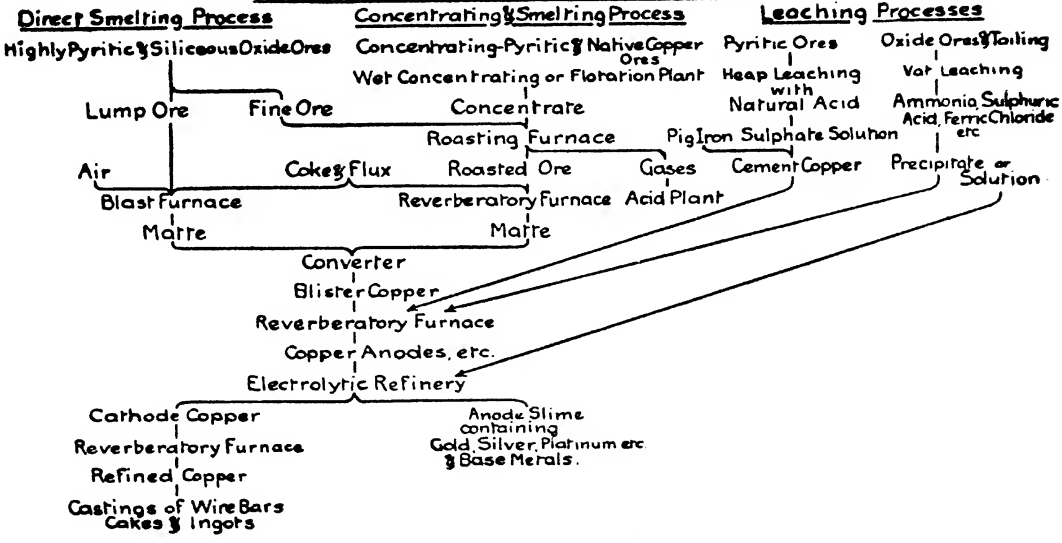
Metallurgy of Copper

The subject of the metallurgy of copper being a very extensive one, it is only possible to treat it in a very general way in this monograph. The methods used in the reduction of copper from its ores are numerous, depending on the nature of the ores and on local conditions. The chart on the opposite page will serve to make clear the following brief *résumé* of the metallurgical processes in use:

Copper reduction processes may be classed under three heads: (1) Direct smelting, (2) Concentrating and Smelting, and (3) Leaching.

Ores suitable for the direct smelting process are either sulphide ores, that are so pyritic that they cannot be economically concentrated, or siliceous carbonate and oxide ores, which cannot be concentrated, mainly owing to their friability. If the ore is coarse, that is in lump form, an air-blast furnace is used for smelting it; if fine, a reverberatory furnace. The blast furnace is vertical and somewhat similar to that used for producing pig-iron. The fuel is nearly always

CHART OF COPPER METALLURGY



Note: Oxide Ores when smelted alone yield Black Copper in one Operation.

coke, and mixed with the ore and flux it is assisted in its work by the combustion of the sulphides. If oxide ores are smelted without an admixture of sulphide ores an impure or "black" copper is produced, together with a slag, in one operation. If sulphide ores are smelted, matte and slag are formed. Matte is a mixture of cuprous sulphide (CuS) and ferrous sulphide (FeS) in varied proportions. The cuprous sulphide has the power of collecting any precious metals present in the ore. Matte in most cases contains from 25 to 55 % copper, 45 % being generally aimed at. Its weight is usually about one-fifth that of the original ore, when the concentration ratio is said to be 5 to 1. During the smelting of a sulphide ore much of its sulphur may be driven off by volatilization as sulphur dioxide. Should an ore contain a very small percentage of copper the resulting matte would be relatively poor, so that it must first be concentrated by roasting. Ores with a copper content below 2 %, and containing small amounts of the precious metals, have been profitably smelted at Bisbee, Arizona.

Reverberatory furnaces are horizontal, the fuel being burned in a separate compartment from that containing the charge, which is smelted on a hearth and heated by radiation from a long flame. The fuel used is either coke, powdered coal, or oil; and matte and slag are formed and tapped off separately as with the blast furnace.

Ores for which the concentrating and smelting process is suitable are either pyritic, or contain native copper; and are concentrated either by the water-concentration method or by the flotation process, the concentrate being afterwards smelted in a reverberatory furnace. A pyritic concentrate is usually roasted beforehand, the resulting sulphur dioxide being generally utilized for making sulphuric acid. Disseminated chalcocite ores with a copper content below 1·3 % have been profitably treated by this process at Bingham, Utah, the recovery being 65 %. At Keweenaw Point, Lake Superior, native copper ores with a copper content as low as 1·3 % have also been profitably treated. Sand tailing of the Calumet and Hecla mine is being treated by the flotation process, which has largely replaced that of water concentration throughout the world.

Matte, whether produced by the blast furnace or by the

reverberatory furnace, is introduced in a molten state into a tilting converter furnace, usually having a siliceous lining, but frequently a basic lining of magnesite, and provided with openings at the bottom through which an air blast is delivered. Sulphur, iron, and other metals are oxidized, the oxides formed either volatilizing, or being slagged with the silica from the lining. The " blister " copper which is produced is remelted and refined in a reverberatory furnace for casting into anodes or other forms. In the process of melting the blister copper air is admitted to oxidize impurities, especially iron, which are collected in the slag. But some cuprous oxide is also formed and is dissolved in the copper. This oxide is removed by " poling " in the following manner : After the slag is removed the molten copper is covered with anthracite or charcoal and then stirred by a pole of green wood. This reduces the cuprous oxide to metal. The anodes by electrolytic refining are converted into cathode copper, whilst the precious and other base metals are deposited as " anode mud," which is refined. Cathode copper is melted in a reverberatory furnace for the production of a highly-refined copper, but as sulphur dioxide is taken up the process of poling is used as in refining blister copper.

This poling process may be avoided by the melting of cathodes in the electric furnace, which is likely to become a standard practice.

Leaching processes are used either for the treatment of heaps of pyritic ore as at Rio Tinto, or for the treatment in vats of oxide ores or tailing. In the former, the heaps of ore, provided with ventilating shafts, are intermittently sprayed with water, and in about four years' time, through the action of sulphuric acid formed by the oxidation of the pyrites, copper, present as sulphide in the original ore, is converted into sulphate, and is precipitated as " cement " copper by pig iron. In vat-leaching processes the solvents generally employed are sulphuric acid and sulphurous acids, ammonium hydroxide or carbonate, for oxidized or native copper ores ; or ferric salts, for ores containing sulphides. The copper is usually precipitated from the solutions by scrap iron, by heat, or by electrolysis. For details of the above processes see the following references : [14] [21 to 32].

Rarer Metals recovered in Copper Refining

The following data of the late Wm. Gowland give the extreme amounts of rarer metals recovered from 100 tons of blister copper (*see* p. 17) at eight electrolytic refineries in different parts of the world:

Gold	from	169	to	2,187 oz.
Silver	,,	550	,,	23,090 ,,
Platinum	,,	0·319	,,	1·825 ,,
Palladium	,,	0·226	,,	6·486 ,,
Selenium	,,	13	,,	170 lb.
Tellurium	,,	0	,,	67·1 ,,
Bismuth	,,	0·33	,,	27·3 ,,
Nickel	,,	11	,,	944 ,,

[33/p. 67].

Anode mud resulting from electrolytic refining (*see* p. 17) may have the following ranges of composition:

Gold, 0·7 to 2·0 %; silver, 5 to 40 %; copper, 10 to 25 %; arsenic, up to 10 %; and antimony, up to 10 % [33/p. 173].

The World's Chief Copper Refineries

In the following table are given some details of the principal copper refining plants of the world [34/1921, p. 98]:

Name of plant.	Location.	Rated Capacity short tons per year.	Product.	Owned by
Tharsis	England	3,500	Refined	Tharsis S. & C. Co.
Briton Ferry	Wales	12,000	B/S, Electro, Sulphate	Cape C. Co.
Trail	Canada	6,200	Electro	Consolidated M. & S. Co.
Port Kembla	Port Kembla, N.S.W.	32,000	Electro & fire refined	Elec. S. & R. Co.
Bowen	Queensland	10,000	Refined	Mt. Elliott Co.
Wallaroo	S. Australia	10,000	Electro & fire refined	Wallaroo & Moonta Co.
Balbach	Newark, N.J.	21,000	Electro & casting	Balbach, S. & R. Co.
Baltimore	Canton, Md.	320,000	Electro	Baltimore C. S. & R. Co.
Chrome	Chrome, N.J.	110,000	Electro & casting	U.S. Metals Ref. Co.
Great Falls	Montana	108,000	Electro & casting	Anaconda C. Co.
Hubbell	Hubbell, Mich.	30,000	Electro	Calumet & Hecla C. Co.
Nichols	Laurel Hill, N. J.	220,000	Electro & casting	Nichols C. Co.
Maurer	Perth Amboy, N. J.	128,000	Electro	American S. & R. Co.

Name of plant.	Location.	Rated Capacity short tons per year.	Product.[1]	Owned by
Raritan	Perth Amboy, N. J.	220,000	Electro	Anaconda C. Co.
Tacoma	Tacoma, Wash. Ter.	90,000	,,	Tacoma S. Co.
Chuquicamata	Chile	80,000	,,	Chile C. Co.
Amagasaki	Japan	7,500	Refined	Furukawa & Co.
Besshi	,,	9,500	B/S	Sumitomo Copper Co.
Denkibundo	,,	6,000	Electro	Denkibundo Co.
Hitachi	,,	45,000	,,	Kuhara & Co.
Kosaka	,,	9,000	,,	Fujita & Co.
Mitsubishi	,,	14,000	,,	Mitsubishi & Co.
Moji	,,	8,500	,,	Nippon Metals & Mfg. Co.
Nikko	,,	30,000	Electro	Furukawa & Co.
Bogoslovsky	Russia	6,000	Refined	S. M. de Bogoslovsk
Caucasus	,,	10,000	,,	Caucasus C. Co.
Kyshtim	,,	10,000	Electro	Kyshtim Corp.
Eisleben, etc.	Germany	20,000	Electro & casting	Manfeld C. Co.

[1] *See* "Grades of Copper" (p. 20).

Cost of Producing Copper

A Federal Trade Commission in the United States investigated the accounts for the year 1918 of 85 domestic (U.S.) and foreign copper mining companies. The companies represented 95½ % of the production of the United States, 94 % that of Chile, 71 % that of Peru, 50 % that of Canada and 20 % that of Cuba.

According to the grade of the ore treated, the costs of the copper produced by 53 American companies, other than Lake or "Porphyry," excluding the values of the precious metal contents, are shown in the following table:

Ore assaying.	No. of companies.	Production. lb. of copper.	Production %.	Average cost per lb. cents. (U.S.).
Below 2%	9	121,431,566	9·69	20·5
Between 2 and 3%	16	178,742,438	14·26	20·9
,, 3 ,, 4%	10	475,109,295	37·89	16·8
,, 4 ,, 5%	8	130,474,902	10·41	15·4
Over 5%	10	348,009,384	27·75	13·4
	53	1,253,767,585	100·00	16·7

The above cost is at Atlantic seaboard and includes all items for labour, materials, supplies and all overhead charges, but not interest or taxes.

The average costs of production of the 85 domestic (U.S.) and foreign companies, according to states and countries, were as follow:

Country or State.	Cost of copper, cents per lb.
Arizona, New Mexico	15·1
Utah, Nevada, California	16·8
Montana, Idaho, Washington	17·4
Michigan	17·6
Other United States	19·9
Mexico, Cuba, S. America	15·6
Canada, Alaska	16·2
Average	16·1

The aggregate investment of the 53 American companies referred to above was $672,000,000, equivalent to 30 cents per pound of copper produced, so that to net 10% on the investment an average profit of 3 cents per lb. would be required.

Descriptions of Copper Productions

The following are descriptions of forms of copper produced by smelters and refiners:

Wire Bars: Used for wire drawing; are from 3 to 4 in. square, and from 3 to 7 ft. long. *Ingots*: Used for casting; weigh from 18 to 20 lb. each. *Ingot or Notched Bars*: Used for casting; are notched and weigh from 55 to 60 lb. each. *Cakes*: Used for rolling; weigh each 100 lb. or over. *Anodes*: Used by electrolytic refiners; are of crude copper, weigh about 250 lb. each and are in size about 2 ft. by 3 ft. by 1½ in. thick. *Cathodes*: In size about 2 ft. by 3 ft. but thicker at the top than at the bottom; consist of refined copper from the electrolytic tanks, which is melted to wire, bars, etc. [35/p. 227].

Grades of Copper

The following classes of copper are dealt with in Great Britain:

Best Selected (*B/S*) : British copper with an average copper content of 99·75 %. It is largely used in the British brass trades, and is of very high purity. It is specially freed from sulphur, arsenic, antimony and iron. *Tough*, or *Tough Pitch*, or *Refined Copper* : A British-refined blister largely consumed in the engineering and shipbuilding trades. It is used for casting, rolling and drawing. It contains about 99·25 % copper, with, usually, about 0·4 % arsenic. *Electrolytic* : Copper refined by the electrolytic process, as cathodes ; contains 99·93 % copper and over ; has high electrical conductivity ; is sold as cathodes, or as ingots and wire bars obtained by melting the cathodes. *Standard* : A term used on the London Metal Exchange for practically any class of metal containing not less than 97 % copper. It may include Chile bars. *Chile Bars* : These are imported into England as bars weighing about 200 lb. each, and containing from 95 to 99 % copper, often with bullion in addition. The metal must be refined. *Matte* : An intermediate yield in the production of finished copper from ore (*see* p. 16). It consists mainly of sulphides of iron and copper, and usually contains from 25 to 55 % copper. *White Metal* : A name for matte consisting almost entirely of copper sulphide. *Bessemer or Blister* : Rough copper produced from white metal (Cu_2S) in Bessemer converters, used for refining.

Three classes of copper are marketed in the United States :

Lake : Copper produced from the native copper mines of the Lake Superior District. It usually contains 99·8 % copper and over, and has an electrical conductivity of over 99·5 %. *Electrolytic* : (*see* above). *Casting* : Metal containing from 98·5 to 99·75 % copper, and produced from ore and from scrap. It is used for casting purposes [34/1922] [35/p. 227] [36/1919].

Typical percentage compositions of commercial grades of copper are shown in the accompanying table :

Analyses of Copper

Grade.	Cu.	Pb.	As + Sb.	Fe.	Bi.	Ni.	S.
Standard bar .	98·70	0·20	0·11	0·10	trace	0·07	0·85
Tough ingot .	99·44	0·165	0·065	0·009	0·004	0·173	—
Fire-box plate .	99·20	0·05	0·546	0·02	0·007	0·09	—
Best selected ingot	99·67	0·10	0·021	0·010	0·005	0·10	—
Best selected ingot	99·71	0·05	0·025	0·007	0·01	0·05	—
Lake wire bar .	—	0·0014 to 0·0044	trace to 0·012	nil to 0·01	nil	—	—
Cathode (unmelted)	—	0·00054	0·0008 to 0·00154	—	—	—	—
Electrolytic wire bar . . .	—	trace to 0·00165	0·0008 to 0·0012	—	trace to 0·00074	—	—

[36/1921, p. 16.]

Prices of Copper

The smelter or refining plant produces copper in the various forms detailed above. Ingots and cakes are known as "unmanufactured" copper, whilst metal which has been subsequently rolled or otherwise treated and turned out as rod, sheet, plate, etc., is said to be "manufactured." For each of the unmanufactured varieties there is a special market price which may be under normal conditions even as much as 65 % above that of the original cost at place of reduction (*see* p. 19). In Great Britain it is usual to publish daily the official prices in pounds (£1) per long ton of the London Metal Exchange for the following varieties of copper: Standard, Best Selected (B/S) and Electrolytic, and in the United States, the prices of the American Export Association, in cents per pound, for the following: Lake, Electrolytic and Casting. In each country the prices differ but slightly from one another.

Recent average annual prices are as follow:

	Standard copper, London.	Electrolytic copper, New York.		Standard copper, London.	Electrolytic copper, New York.
	£ per long ton.	Cents per lb.		£ per long ton.	Cents per lb.
1912	73·00	16·48	1917	125·12	29.19
1913	68·29	15·52	1918	115·58	24·68
1914	59·56	13·32	1919	90·97	18·69
1915	72·66	17·47	1920	97·48	17·46
1916	116·06	28·46	1921	69·36	12·90

In the United Kingdom the selling of copper was controlled between June 1917 and December 1918, the official price varying during the period. In the United States the Government fixed the price at 23½ cents on September 21, 1917, and again, on July 2, 1918, at 26 cents: in December 1918, unrestricted selling was resumed.

Secondary Copper

Unlike most of the other base metals, scrap copper, whether as metal or in the form of alloy, can be used over and over again, and when remelted is known as secondary copper. In fact, of all the copper produced, only that small proportion, chiefly that used in the manufacture of brass pins, insecticides and chemicals, is lost. In the big manufacturing countries, especially the United States, Germany and England, much copper is reworked and made use of, and productions are recorded in addition to those of new or primary copper. For the handling and treatment of scrap material reference [37] may be consulted.

Associations of Buyers and Sellers of Copper

The following contains a list of the metal exchanges and the principal groups associated with the production and marketing of copper [38].

Associated Copper Smelters.—As mentioned above (p. 2) there was formed in England in the early part of the nineteenth century an association of smelters which largely controlled the market for copper for a period of about fifty years. This was possible, and, indeed, may be said to have been inevitable, from the fact that the smelting of copper for the whole world was largely concentrated at that period in the United Kingdom, mainly in the vicinity of Swansea in South Wales.

London Metal Exchange.—This was founded in 1869 and consists of about 150 members. Before the war it was, and even at the present time is, the only free market in the world in non-ferrous metals, and consequently its quotations have determined in the past, and largely determine to-day, the prices of copper all over the world.

New York Metal Exchange.—This was formed in or about the

year 1885, and was modelled on the lines of the London Metal Exchange. Its operations, however, have never assumed any considerable proportions, and the Conference on Reconstruction in the United States, held recently, declared that it was not sufficiently representative of the metal interests, and advised the formation of a representative exchange. In consequence of this an attempt is being made to develop its activities again, taking the London Metal Exchange as its model. In co-operation with the London Metal Exchange a system to co-ordinate statistics is being evolved.

Hamburg Metal Exchange.—This was established in about the year 1911 professedly on the lines of the London Metal Exchange. Up to the outbreak of war the business done was on a very small scale, and it had no influence on the world's markets, the prices quoted at its daily meetings in the afternoon being those of the London market of the same day received by telegram.

Australian Metal Exchange.—This was formed in 1917 under the auspices of the Commonwealth Government. Its main function is to register all sales for export in accordance with a Government regulation. Membership is subject to the approval of the Attorney-General of Australia and is confined to British-born subjects.

The control of the copper resources of the world has largely passed during the last forty years to the United States of America, whose production during that period has become the predominant factor in world supplies. There were, and are still, four main groups, namely:

The Lake Companies.

The Lewisohn Group.—Mainly in Montana, turned over first to the Amalgamated Copper Co. and now to the Anaconda Co.

The Guggenheim Interests, until recently entirely merged in the American Smelting and Refining Co., but now partially divided.

The Phelps Dodge Group, chiefly concerned in the production in Arizona.

Modifications of these groupings are constantly taking place as copper is found in other districts, this copper generally

coming under the influence of one or other of these groups, who on the foundation of their large productions have built up refining plants so extensive as to be able to operate more economically than any competitors. Selling organizations are attached to each group.

Under the Webb law, which made it possible for American interests to combine for the purpose of export business, the *Copper Export Association of America* was formed in 1918, all the groups mentioned being members of it and representing approximately 70 % of the United States output of copper. Outside this association, there is, however, the *American Metal Co.*, which, since the war, has absorbed the *Vogelstein-Hirsch Interests*, and which represent a capacity of about 160,000 tons per annum.

There were powerful commercial organizations before the war which had considerable influence on the copper market. The most notable of these was the *Metallgesellschaft* of Frankfurt-am-Main, which was in close association with *Henry R. Merton & Co.* of London and the *American Metal Co.* of New York, and *Aaron Hirsch & Sohn* of Halberstadt, who were similarly connected with *L. Vogelstein & Co.* of New York, and who, moreover, mainly through their interest in the Electrolytic Smelting and Refining Co. of Port Kembla, were able to control about one-third of the Australian production of copper. The German elements in the American Metal Co. and L. Volgelstein & Co. are understood to have been replaced by American interests, and these two concerns are now amalgamated and trade under the name of the American Metal Co. In Germany the Metallgesellschaft and Hirsch interests are also now closely associated, at any rate so far as copper and some of the other metals are concerned.

In England a powerful British association, the *British Metal Corporation, Ltd.*, was established in 1918 to act as a counterweight to the associations abroad and to help the general trade of the Empire in non-ferrous metals. This organization operates in close co-operation with the very important producers in the great British Overseas Dominions.

General Properties of Copper

When pure, copper has a characteristic salmon-red colour, is ductile, tough, and highly malleable, and takes on a brilliant polish. It is one of the best conductors of heat and electricity known. For conductors of the same diameter, the conductivity of copper for heat is about 92 % that of silver, and for electricity, nearly equal to that of silver. For conductors of equal weight the electrical conductivity of copper is half that of aluminium.

Copper has a specific gravity of 8·96 and melts at about 1110°C. Its specific heat is 0·09. It has been distilled in an electric furnace. The tensile (breaking) strength of cast copper is 29,000 lb. per sq. inch, compared with 100,000 for ordinary crucible cast steel with 0·9 % carbon.

When molten, copper absorbs carbon monoxide, hydrogen and sulphur dioxide, and decomposes hydrocarbons, absorbing the hydrogen and depositing the carbon; hence to avoid porous castings precautions are necessary when melting copper.

Most ores from which copper is extracted are complex, so that the number of impurities it may contain are many and may affect its properties, unless eliminated by refining (*see* p. 13).

Uses of Copper

In times of peace copper is used more in the electrical industries than in all others together. It is employed for vessels of all sorts used in brewing, distilling and chemical work; for plates in copper printing; in manufacturing bronze and brass, and for coinage. Much copper is employed in the fireboxes of locomotives, in construction of machinery generally, and in bearing alloys. In shipbuilding it is largely used for machinery and fittings, and especially in passenger ships for steam heating pipes. The automobile industry also absorbs much copper, the amount of copper in the form of alloy and metal used varying from about 20 lb. to about 200 lb. per car, according to its class.

Copper is now being used in alloy with steel, in amounts generally about 0·25 %, to reduce its tendency to corrode.

Cupro-silicide or cuprosilicon, an alloy of silicon and copper made in the electric furnace, is used for hardening copper, and is added to zinc, tin, and copper-aluminium alloys, to increase their tensile strengths.

Chloride of copper ($CuCl_2$) is used as a powerful disinfectant; also in calico printing and in certain chemical processes. Sulphate of copper is used in calico printing, in dyeing, for preventing rot in timber, and in the preliminary treatment of seeds as a safeguard against smut. It is applied also, in solution, to grape vines and other plants, to prevent fungoid growths, and also to kill algæ and other vegetation in reservoirs and ponds. Copper salts are used for the staining of glass.

Malachite and azurite, the native carbonates of copper, when finely ground, are used to a large extent in the making of brilliant, but expensive, paints. Malachite is also used for making ornaments.

Alloys of Copper

Over four-fifths of all non-ferrous alloys in use contain copper, generally as the chief ingredient. The following are some of the more important binary and ternary alloys of copper [36/1919]:

Copper-Tin Group (*Bronzes*).—Copper and tin are the chief and essential constituents. The principal alloys are as shown in the first table on page 28.

The principal element of bronzes, as will be seen below, is copper. Tin hardens the copper. The chief function of modern bronzes is their substitution as ternary and quaternary alloys for the old binary alloys of tin and copper. Bronzes take on a high polish: they have metallic lustre, have low melting points and are easily cast.

Copper-Zinc Group (*Brasses*).—Copper and zinc are the chief and essential constituents. These unite in all proportions. The principal alloys are shown in the second table on page 28.

There is a great variety of brasses: they are more numerous than the bronzes. They are cheaper than either bronze or copper and are mainly used for constructional and ornamental purposes. Brasses are very fusible and make good castings.

Name.	Copper.	Tin.	Remarks.
	%	%	
Speculum Metal	66·6	34·4	Arsenic, antimony, lead, nickel sometimes added to increase hardness.
Bell Metal .	77 to 80	23 to 20	Used for bells; heavy machinery bearings.
Gun Metal .	90	10	Used for shipbuilding; signal guns; non corrodible.
Admiralty Gun-metal . .	88	10	+ 2% zinc.
Harder Alloy .	86	12	+ 2% zinc: used for hydraulic work.
Railway Alloy .	84	8·5	+ 5% zinc + 2·5% lead.
Phosphor Bronzes (with great ranges of ductility, hardness, and tensile strength) .	94·1	4·75	+ 0·53% phosphorus.
	90·3	8·90	+ 0·77% phosphorus.
	82·0	13·0	+ 0·6% phosphorus + 1·0% zinc + 3·4% lead.
	90·9	8·9	+ 0·2% phosphorus.
	89·5	10·0	+ 0·5% phosphorus.
	86	11·6	+ 0·9% phosphorus + 1·5% zinc.
Silicon Bronze	97·37	1·32	+ 1·24% zinc + 0·7% silicon; greatly used for telephone and telegraph wires, having high conductivity, being stronger than copper, and more durable than steel.
Manganese-copper Alloys[1] .			Cheaper substitutes for real bronzes being cupro-manganese alloys, often without tin. Sometimes the manganese content is as high as 40%.

[1] The term "Manganese Bronze" is used, wrongly, on the market for brasses containing about 60% copper and 40% zinc, with manganese only in very small quantity.

Name.	Copper.	Zinc.	Remarks.
	%	%	
Delta Metal .	56·4	42	+ 1·2% iron; 0·37% phosphorus; 0·10% lead; % of zinc may vary from 40–43. Alloy has great tensile strength, up to 75,000 lb. per sq. in. and may be forged
Muntz Metal .	60	40	Used for all parts of ships exposed to sea water.
Naval Brass .	60–62	39–36·5	+ 1 to 1·5% tin.
"Strong" Brass	58	38	Largely used for pumps.
Yellow Brass .	66	34	A common formula } Lead often replaces zinc or copper to cheapen.
	80	20	A good ,, }
Mosaic Gold .	66	34	Alloys usually gilded.
Art Brass .			
Pinchbeck, etc.			
Cartridge Brass	70	30	The toughest and strongest of all brasses.
Brass Wire .	70·30	29·25	+ 0·28% lead and 0·17% tin.
Brass Sheet .	84·70	15·30	
Valve Brass .	80	15	+ 3% lead and 2% tin.
Statuary Brass	91·50	5·5	+ 3·30% lead and 1·70% tin.
"Bronze" powders . .	various	over 18	+ other metals to get different colours.

Copper-Zinc-Nickel Group.—Copper and nickel are the chief constituents, copper predominating. The various alloys are usually classed under the name, nickel silver. They often contain lead, iron, manganese and cobalt. The following are the compositions of a few:

Name.	Copper.	Zinc.	Nickel.	Remarks.
	%	%	%	
Chinese Packfong	40·8	44·3	15·2	+ up to 3% iron. The original alloy was first made in China.
Nickel Silver	52	26	22	Similar alloys used for coinage.
An English Alloy	51·6	22·6	25·8	
A French Alloy	50	31·3	18·7	
Chilean coinage	70	10	20	
An expensive alloy	46	20	34	Noted for beauty, lustre and working properties.
Platinoid	60	24	14	+ 1–2% tungsten. Used for electrical resistance.

These nickel silver alloys possess whiteness, hardness, toughness, ductility, and resistance to certain chemicals. They are used for foreign coinage, for table utensils and for ornamental work, and, by the French, for jewellery when alloyed with silver.

Copper-Aluminium Group (inappropriately called "Aluminium Bronzes").—These may contain little or no tin. The amount of aluminium present may vary from 1 to 10%. These alloys have great tensile strength, but low elongation.

The aluminium alloys are mainly used for bearing metals, for forging, for wire drawing and for rolling into rods or sheets. The alloy with 10% aluminium is almost exactly the colour of gold, and as it is little subject to corrosion it is much used in engineering: it would be more used if easier to cast and work. Duralumin, containing 4% copper, 95% aluminium and the balance silicon and magnesium, is largely used in aeroplane construction.

Monel Metal.—The alloy of copper and nickel known as monel metal is produced directly by the melting of the ores of Sudbury, Ontario. It is silver-white, but assumes a blackish-grey colour on prolonged exposure to the air. It is exceedingly ductile, can be rolled into thin sheets, and drawn into a very

fine wire. It resists acids, the atmosphere of the sea, and that of a manufacturing city.

Its composition varies as follows: Nickel, 68 to 72%; copper, 27 to 32%; iron, 0·5 to 1·5% ; carbon, 0·072 to 0·1; copper, 27 to 32%; iron, 0·5 to 1·5%; carbon, 0·072 to 0·15%, and sulphur, 0·014%; but, notwithstanding these variations, its physical properties are not appreciably affected. It melts at 1350° C, has an annealing temperature of 875° C, and can be rolled at temperatures between 900° and 1200° C. It retains 80% of its tensile strength at 550° C, whilst ordinary steel retains only 7% at the same temperature. Its breaking strength is 86,899 lb. per sq. in. with hot-rolled rods and 37,427, with sand-cast rods. Further information will be found in references [39 to 42].

Substitutes for Copper

A number of substitutes for copper have been made use of in recent years, especially during the war, aluminium being the chief, and the next, in a much less degree, zinc. German experts maintained that one-third the former requirements of copper could be replaced by aluminium, and owing to this estimate large aluminium factories have lately been built in Germany, where the 1920 production of the metal was 40,000 tons compared with about 1,000 tons before the war.

Copper and brass-covered materials have largely replaced the metals themselves, but with a loss of resistance to corrosion. Domestic utensils of aluminium and galvanized iron, and, in the United States, of monel metal and armco iron, have to a great extent been substituted for those of copper. In the manufacture of pins, brass has been largely replaced by steel.

In the automobile industry the amount of copper used per car is now often reduced by the substitution of other metals.

In the electrical industry till recently the position of copper was considered supreme, but for some purposes, especially for high-tension transmission work, aluminium has replaced it to some extent, especially in France, Germany and Switzerland. According to *Electrotechnisk Tidsskrift* aluminium entirely took the place of copper in the manufacture of a synchronizing

transformer of 38,000 kw. capacity. The main objection to the substitution of aluminium for copper in electrical machinery is the cost of insulation owing to its size; accordingly its use is extending only in the case of bare conductors.

Consumption of Copper

In different countries the consumption of copper varies greatly, being very little in some and very great in others, where much manufacturing is carried on. According to B. S. Butler [8/p. 142], the average annual consumption of the world, *per capita*, before the war, was 1·3 lb., whilst in certain industrial countries it was as follows: Germany, 8·5; United States, 8·1; United Kingdom, 6·7; France, 5·8 and Russia 0·5 lb.

The following table gives rough estimates of copper consumptions in the United States, classified under different headings, for the years 1919 and 1920:

Current Copper Consumption (U.S.A.)

	1919.		1920.	
	Short tons.	Percentage.	Short tons.	Percentage.
Electrical manufactures	130,000	35·6	170,000	29·8
Telephones and telegraphy	42,500	11·4	50,000	8·8
Wire, not included elsewhere	55,000	14·8	95,000	16·7
Automobile industries	27,000	7·2	49,650	8·7
Railway locomotives and cars	7,000	1·8	8,800	1·6
Shipbuilding	12,000	3·2	35,750	6·3
Ammunition	7,000	1·8	11,700	2·1
Bearing metal for steam railways	20,000	5·4	22,500	4·0
Buildings	20,000	5·4	26,700	4·7
Other uses	50,000	13·4	98,500	17·3
Total consumption (U.S.A.)	370,500	100·0	568,600	100·0
Exports of manufactured copper	32,000	-	82,000	—
Totals	402,500	- -	650,600	—

[43]

Control of the World's Copper Resources

According to the estimates of F. W. Paine, the geographical and financial control of the world's copper mines is distributed

as shown in the table on page 33. Based upon the annual refining capacities of different countries, business control is exhibited in the table on page 34, whilst on page 35 the table shown gives the relative importance of different countries as regards their control of the copper ore reserves of the world. It will be noticed from the estimates that the United States' invested capital is 69%, and British, 13·3%, of the world's present estimated output capacity based on ore production; that the United States command 69·7%, British countries 11·3%, and Japan 7·6%, of the world's refining capacity; and that, of the world's known reserves of ore, the United States control 73·6%, and British countries, 20·8%.

Geographical and Financial Control of the World's Copper Mines (F. W. Paine)

(Annual Production of Metal in Metric Tons)

Percentage of world total.	Average 1916–17 output.	Country.	Estimated output capacity.	Percentage of world total.	Invested capital in proportion to tonnage.					
					U.S.	British.	German.	French.	Japanese.	Local.
59·2	863,903	United States	928,000	57·5	890,000	29,000	—	—	—	—
3·3	49,168	Canada	58,000	3·6	28,000	30,000	—	—	—	—
3·4	49,478	Mexico	65,000	4·0	49,000	idle	2,500 +	13,500	—	—
1·0	14,000	Cuba	10,000	0·6	—	—	2,000 +	—	—	8,000
0·2	2,000	Venezuela	2,000	0·1	—	2,000	—	—	—	—
4·8	70,000	Chile	110,000	6·8	80,000	2,500	4,500 +	9,500[1]	—	7,500
3·0	43,620	Peru	45,000	2·8	45,000	—	—	—	—	—
0·4	6,000	Bolivia	12,000	0·8	6,000	—	—	6,000	—	—
3·2	47,750	Africa	58,000	3·6	—	58,000[1]	—	—	—	—
2·5	36,550	Australia	43,000	2·7	—	43,000	—	—	—	—
7·9	112,000	Japan	125,000	7·7	—	—	—	—	125,000	—
2·9	42,000	Spain and Portugal	42,000	2·6	—	40,000	—	—	—	2,000
1·3	18,500	Russia (?)	18,000	1·1	—	—	18,000 (?)	—	—	—
4·8	71,000	Central Powers (?)	71,000	4·4	—	—	71,000	—	—	—
1·4	19,000	Norway	10,000	1·2	—	10,000	—	—	—	9,000
0·1	1,000	Sweden	1,000	0·1	—	—	—	—	—	1,000
0·4	6,250	Other countries	6,250	0·4	—	250	—	2,000	—	3,000 (Italy) 1,000 (China)
100·0	1,456,869	—	1,613,250	100	69%	13·3%	6·1%	1·9%	7·7% (?)	2%

[1] Includes Belgian capital

[44/p. 224].

Business Control of World's Copper Mines (F. W. Paine)

(Annual Refining Capacities in Metric Tons)

Country of origin.	Estimated capacity output of copper.	Refined in						Formerly sold by German houses.
		U.S.	British Dominions.	Germany.	France.	Japan.	Other countries.	
United States	928,000[1]	928,000	—	—	—	—	—	(73,000)
Canada	58,000[1]	28,000	30,000	—	—	—	—	(21,000)
Mexico	65,000[1]	52,000	—	—	13,000	—	—	(2,500)
Cuba	10,000[1]	10,000	—	—	—	—	—	(10,000)
Venezuela	2,000[1]	2,000	—	—	—	—	—	—
Chile	110,000[1]	43,000	2,500	—	9,500	—	55,000[2]	(20,000)
Peru	45,000[1]	45,000	—	—	—	—	—	—
Bolivia	12,000[1]	9,000	—	—	6,000	—	—	—
Africa	58,000	5,000	53,000	—	—	—	—	(5,000)
Australia	43,000	—	43,000	—	—	—	—	(43,000)
Japan	125,000	3,000	—	—	—	122,000	—	—
Spain and Portugal [3]	42,000	2,000	35,000	—	5,000	—	—	—
Russia	18,000 (?)	—	—	—	—	—	18,000 (?)	(?)
Central Powers	71,000 (?)	—	—	71,000 (?)	—	—	—	(?)
Norway	19,000	—	19,000	—	—	—	—	(?)
Sweden	1,000	—	1,000	—	—	—	—	(?)
Other countries	6,250	—	250	—	2,000	—	{ 3,000 (Italy) 1,000 (China)	—
Total and Percentages	1,613,250	69·7%	11·3%	4·4%	0·4%	7·6%	4·8%	(11½%)

[1] The United States controls substantially the sale of N. and S. American copper or 76·2% of total.
[2] Chile copper: U.S. owned.
[3] Estimated.

Future Importance of Present Copper Producing Countries as indicated by Known Reserves of Copper Ore, and the Capital controlling these Reserves (F. W. Paine)

Producing country.	Estimated capacity output of copper.	Percentage of world total.	Developed reserves in terms of years' life at capacity output and controlling capital.[2]						Product of percentage and years.[3]	Percentage of total reserves of world.
			U.S.	British.	German.	French.	Japanese.	Local.		
	Metric tons.		Years.	Years.	Years.	Years.	Years.	Years.		
United States	928,000	57·5	12·4	12·4	—	—	—	—	713	34
Canada	58,000	3·6	15	20	—	—	—	—	63·3	3
Mexico	65,000	4·0	5	large	large	6	—	—	20·8	1·15
Cuba and Venezuela	12,000	0·7	—	—	3	—	—	3	2·1	0·10
Chile	110,000	6·8	150	3	(?)	5	—	considerable	795·8	37·9
Peru	45,000	2·8	4	—	—	—	—	—	11·2	0·55
Bolivia	12,000	0·8	—	—	—	4	—	—	2·8	0·10
Africa	58,000	3·6	—	66[1]	—	—	—	—	237·6	11·3
Australia	43,000	2·7	—	7·2	—	—	—	—	20	0·95
Japan	125,000	7·7	—	—	—	—	6	—	46·2	2·2
Spain and Portugal	42,000	2·6	—	50	—	—	—	50	130	6·2
Russia	18,000	1·1	—	18 (?)	18 (?)	—	—	18	19·8	0·95
Central Powers	71,000	4·4	—	—	5 (?)	—	—	5 (?)	20	0·95
Norway	19,000	1·2	—	10	—	—	—	10	12	0·55
Sweden	1,000	0·1	—	—	—	—	—	10	1	0·04
Other countries	6,250	0·4	—	—	—	—	—	(?)	1·4	—
Totals and Percentages	1,613,250	100	73·6%	20·8%	1·05%	0·4%	2·2%	1·95%	—	—

[1] Katanga = ⅔ of this.
[2] Not too much weight is to be attached to figures showing more than 10 years of life.
[3] The product gives total ultimate relative importance of different countries.

[44/p. 226].

World's Production of Copper

The table below gives recent outputs of copper of the chief copper producing countries of the world, which have been taken almost entirely from official sources. Copper productions for different periods are also exhibited graphically in the diagrams on pages 38 to 40. In the diagram on page 37 are plotted the average prices of English copper since 1801.

World's Production of Copper (*a*).

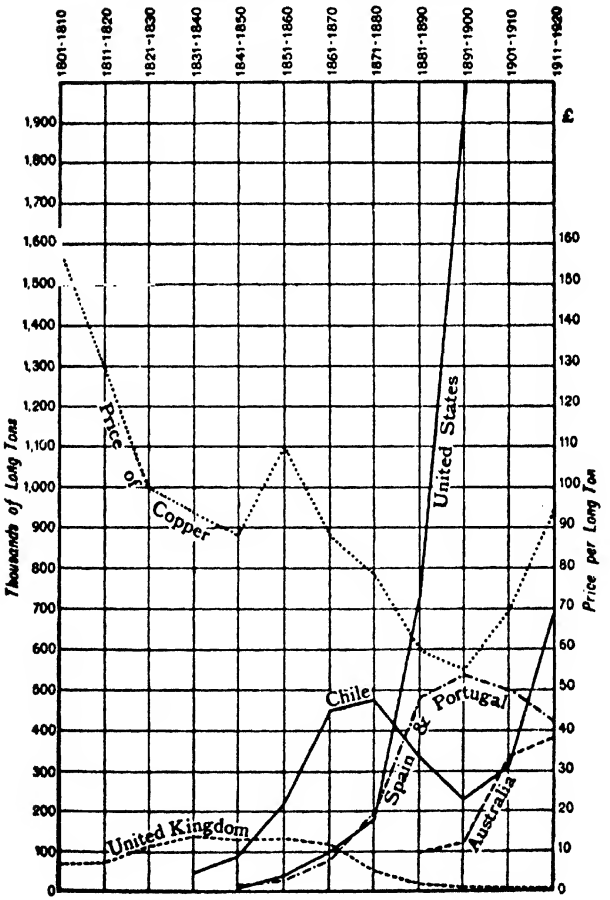
(Metric Tons)

	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.8
United States	497,701	563,943	555,422	521,699	629,597	874,467	855,539	865,705	583,516	548,426 [6]	229,331
Japan [1]	53,402	62,423	66,501	70,463	75,416	100,630	108,038	90,341	78,443	67,792	53,392
Chile	36,420	41,647	42,263	44,665	52,341	71,288	102,527	106,814	70,000 [7]	94,531 [8]	55,721
Mexico	59,421	55,068	52,800	36,337	20,598	28,411	50,986	70,223	56,172 [8]	46,057 [8]	15 228
Canada [2]	25,242	35,304	34,916	34,354	45,716	53,139	49,549	53,873	34,044	37,014	24 258
Peru	27,735	26,969	27,776	27,090	34,728	43,078	45,176	44,414	39,230	31,276 [6]	33,800
Spain	49,211	61,018	31,248	25,706	34,699	32,880	38,526	45,104	23,419	21,500 [9]	27 500[9]
Germany	22,600	27,400	26,600	25,100	26,300	31,000	27,000	25,000	26,000	27,000	19 000[9]
Australia [3]	46,236	46,377	46,786	40,433	39,912	40,109	40,166	39,594	19,567	27,123	11,000[9]
Russia [4]	25,097	33,513	33,795	31,414	25,599	21,487	16,000[8,9]	5,000[8,9]	—	—	—
Belgian Congo [5]	997	2,492	7,245	10,772	14,040	22,149	27,463	20,238	23,028	18,962	30,470
Other countries [9]	47,000	47,500	44,000	44,500	44,500	45,000	55,000	66,500	32,000	29,500	31 900
World's Total	891,062	1,003,654	969,352	912,533	1,043,446	1,363,734	1,415,970	1,432,806	985,419	940,139	531,600

(*a*) "Copper in 1920," *U.S. Geol. Survey*, 1920, pt. i.

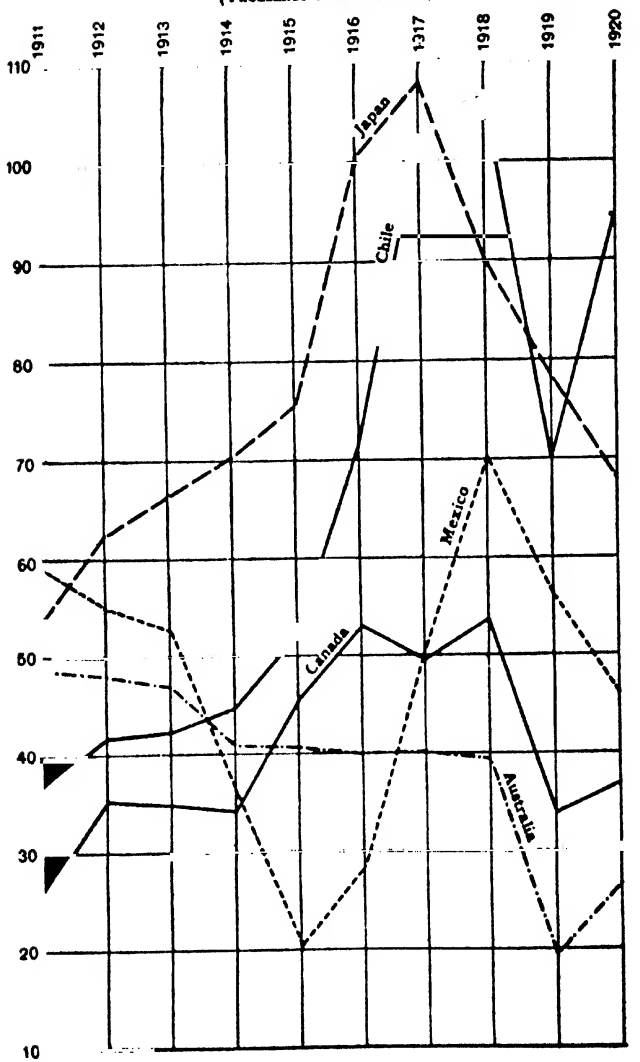
[1] *Financial and Economic Annual of Japan*, and *Bd. Trade Journ.*, September 15, 1921.
[2] *Ann. Repts. Min. Prod. Canada.*
[3] *Mines Repts.* of N.S.W., Queensland, etc.
[4] "*Ironmonger*," *Metal Market Year Book*, 1921.
[5] Skinner, W. R., *Min. Manual and Min. Year Book.*
[6] *Mineral Industry*, 1921.
[7] *Bd. Trade Journ.*, November 11, 1920.
[8] *U.S. Comm. Rept.*, No. 30, February 5, 1921.
[9] Estimated.

Outputs of Chief Copper-producing Countries and Average Price of English Copper by Decades in the Period 1801-1920 [1]



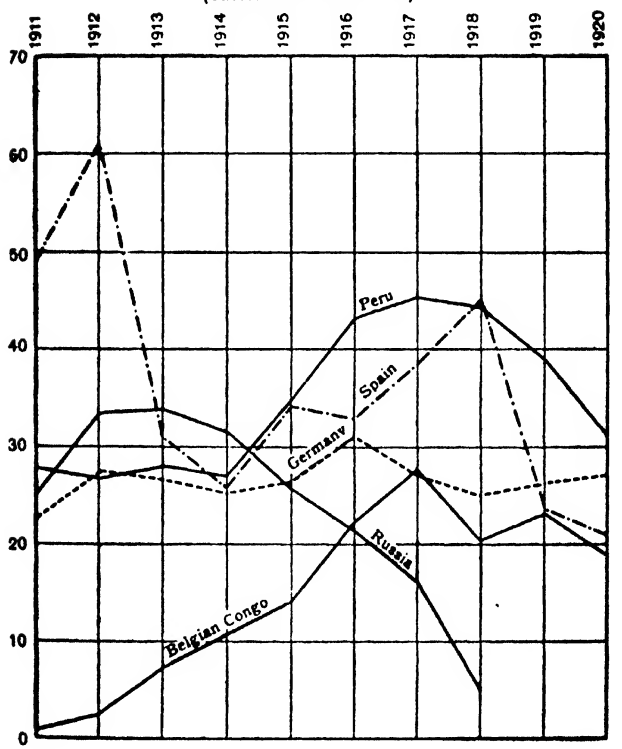
Note:- *Outputs of the United States for the periods 1901-1910 and 1911-1920 were 3,823,000 and 6,404,000 tons respectively*

Outputs of Various Copper-producing Countries, 1911-1920
(Thousands of Metric Tons)

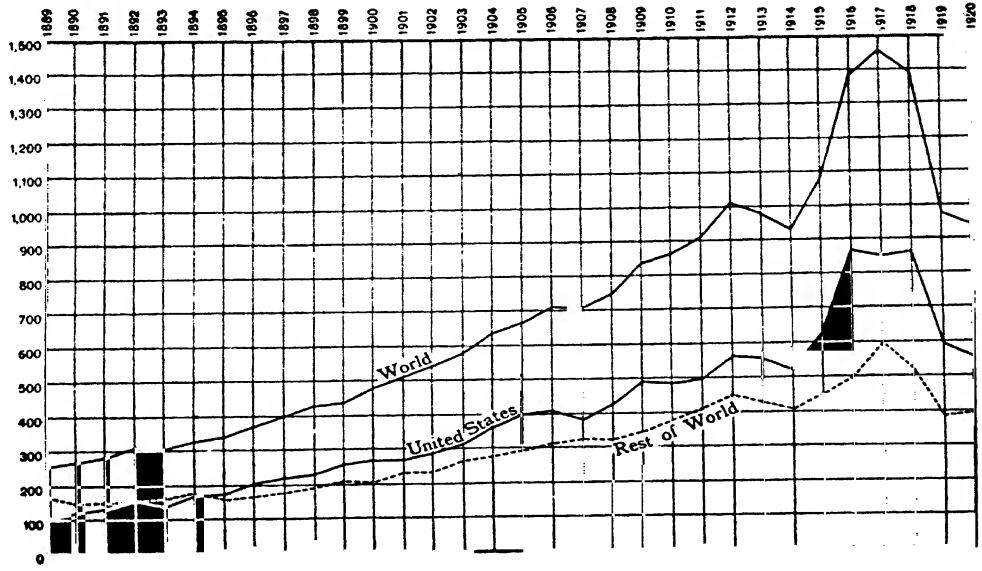


Outputs of Various Copper-producing Countries, 1911-1920

(Thousands of Metric Tons)



Relative Copper Outputs of the United States and the Rest of the World, 1889-1920
(Thousands of Metric Tons)



CHAPTER II

SOURCES OF SUPPLY OF COPPER ORES

(*a*) BRITISH EMPIRE

EUROPE

England and Wales

At one time, as mentioned before, the British Isles supplied almost three-quarters of the copper output of the world, Cornwall, Devon, and Anglesea being the chief producing counties. Since about 1880 production has been insignificant, and the copper mines are mostly of historical interest only.

It is probable that the Phœnicians mined both copper and tin ores in Cornwall and Devon between 2,000 and 3,000 years ago. The lodes there occur in the metamorphic areas between large masses of granite and Devonian or Carboniferous sedimentary rocks. The lodes are often associated with *elvans* or quartz-porphyry dykes, and usually contain tin in the older or lower parts of the lodes, and copper sulphides in the upper parts. This is especially likely to be the case when the lode cuts the *killas*, or sedimentary rock, above, and granite below [45/p. 88]. In recent years in Cornwall copper ore has been produced only in very small amounts as a by-product, principally at the Tincroft mines.

Copper ore was mined first in Anglesea on Parys Mt. by the Romans, but there was no systematic work till 1768. The ores yielded about 5½% copper. In Carnarvonshire near Nantlle is an old mine, the Drws-y-coed, formerly worked to a depth of 500 ft. In the Isle of Man a very small amount of ore has been produced at Bradda Head.

In Cheshire copper-mining was formerly carried on at Mottram St. Andrews, but never profitably. The ore contains the vanadium mineral, mottramite. At Alderley Edge are bedded deposits of sandstone and conglomerate, cemented with copper carbonates. The ore contains about 1½% copper with traces of cobalt. The lowermost bed, sometimes 66 ft. thick, dips at 20° and was worked to a depth of 1,800 ft. in 1894.

Carbonate ores have been worked in the Red Triassic rocks in Somerset, near Doddington, and near Bridgewater.

An old mine at Newlands, near Keswick, Cumberland, was worked for 250 years from about the year 1250. The Ecton mine on the borders of Staffordshire and Derbyshire was also in operation in early times. Its principal deposit is an almost vertical pipe in limestone, but a number of lodes, both E.W. and N.S., occur. Blende with copper ores is present below galena. In depth chalcopyrite and bornite predominate.

Chalcopyrite lodes occur on the east side of the Plynlymmon Range in Cardiganshire and Montgomeryshire. Intermittent mining on the pyritic lodes on the Vigra and Clogau mountains in Merionethshire has taken place: one lode was worked for gold later on.

Scotland

Copper ores have been mined in Scotland from ancient times. Stone moulds for casting bronze have been found in Aberdeenshire and probably date from 1500 to 1800 B.C. There are over 50 old mines, most of them long abandoned, mainly in the counties of Kirkcudbrightshire, Argyleshire and Clackmannanshire, which have been described fully by G. V. Wilson. [46/p. 120]. No mines are in operation at the present time. In the Orkneys, in the island of Burray; in the S.E. of the mainland of Shetland; and on Fair Isle, copper deposits have been worked and have been described by J. S. Flett [46/p. 148]. The Sandlodge mine, Shetland, which was abandoned in 1881, was reopened and unwatered in 1920. The results of a resampling in 1921 were disappointing.

Ireland

In Co. Wicklow are several old copper mines on a belt extending for 6 miles N.E. from Ovoca, the lodes being in slate and schist country and associated with pyroxenic and felspathic rocks, mostly metamorphic. It is reported that examinations made recently showed the presence of much low-grade ore, and the reworking of the mines has been under consideration. At West Cronebane is a large E.W. pyritic vein, containing 2% copper in parts: mineralized country occurs both to the north and south. In the latter are lenticular copper deposits. The Kilmacoo lode farther N.E. contains silver from 6 to 8 oz. per ton. Various copper lodes in the district contain 8 to 12% copper. Operations have ceased for many years.

In Co. Waterford, in the Bunmahon district, the Knockmahon mines formerly were good producers, but operations were suspended in 1880.

In Co. Cork copper lodes discovered in 1810 at Allihies, near Castletownbere, were worked to a depth of 1,500 ft. Operations were suspended about 1882. Another copper mine is at Brow Head near Crookhaven [47].

Tables of Imports and Exports of copper of the United Kingdom are given on pages 44 and 45, and domestic productions are as follow:

Production of Copper in the United Kingdom [48]. *Metal content of dressed ore and precipitate*

(Long tons)

1913	421	1918	179
1914	341	1919	144
1915	235	1920	127
1916	278	1921	nil
1917	187		

Of the above, Ireland produced for the years 1913–16, only 42, 3, 4, and 7 tons, chiefly from Meath and Wicklow.

Prices of copper in London are given on page 22 and are also shown graphically on page 37.

Imports of Copper into the United Kingdom [49]

(Long tons)

	1913	1914.	1915.	1916.	1917	1918	1919.	1920.	1921.
Dressed Ore	8,484	6,442	3,400	3,088	1,490	1,379	1,223	1	1
Estimated Metallic Content . . .									
Regulus and Precipitate . . .	16,427	17,570	15,812	18,105	11,662	8,678	7,156		
Estimated Metallic Content . . .									
Old Copper for remanufacture . .	4,400	3,449	2,131	2,237	1,055	122	1,021	1,840	—
Unwrought Copper: bars, blocks . .	104,678	147,714	174,904	108,131	140,840	203,317	109,319	104,428	84,320
Copper Part wrought	2,270	2,762	5,482	3,281	1,938	626	5,683	7,448	2,490
Copper Manufactures	12,907	10,267	6,398	1,582	1,559	1,708	2,755	18,122	—

Estimated percentage of total imports from Foreign Countries and from British Possessions for the above period were: Copper Ore, 66 and 34%; Regulus and Precipitate, 61 and 39%; and Unwrought Copper, 85 and 15% respectively.

[1] Copper ore including regulus, matte, precipitate, etc. imported, amounted in 1920 to 31,164 tons; in 1921 to 30,833 tons.

Exports of Copper from the United Kingdom [49]

(Long tons)

I. British Dressed Ore and Metallic Copper produced mainly from Foreign Ores

	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Dressed Ore	200	313	—	—	—	—	—	} 1,951[1]	{ nil
Regulus, Matte, Precipitate and Residues	1,870	1,553	1,220	1,472	1,101	516	325		{ nil
Unwrought, Ingots and Slabs, etc.	14,907	7,249	6,657	9,189	5,177	4,034	10,735	14,685	10,885
Mixed or Yellow Metal	14,472	13,202	3,809	1,614	464	223	7,515	19,064	—
Wrought Copper of other sorts	21,959	18,088	13,800	8,014	3,417	2,485	15,323	25,578	18,679

[1] Also 1,924 tons of scrap and old metal for remanufacture.

II. Foreign and Colonial Produce (Re-Exports)

Dressed Ore	493	136	—	1	—	—	588	} 2,604
Regulus and Precipitate	723	—	—	—	15	—	—	
Old Copper for re-manufacture	77	77	—	—	—	—	—	47
Unwrought, Bars, ingots, etc.	19,278	10,523	7,300	7,330	3,127	672	7,607	15,440
Part wrought	24	163	40	5	—	—	311	1,370
Copper Manufactures	229	161	404	65	4	2	371	156

ASIA

British Borneo

(British North Borneo, Brunei and Sarawak)

Traces of copper are found in upper Sarawak, not far from the boundary with Brunei, and malachite and azurite occur in small quantities in the antimony veins of the Busan Hills.

In British North Borneo chalcopyrite, sometimes accompanied by pyrite, has been found in quartz-veins in serpentine (?), and also in small quantities, with abundant pyrite, in a vein of calcite in compact limestone. Other ores of copper occur sparingly in various places [50].

In 1908 pyritic ore was discovered in the Karamuak, a tributary of the Kinabatangan River, which flows into the Sulu Sea on the N.E. coast. An analysis showed 5·62% copper, besides gold, silver, iron and sulphur [51].

Cyprus

Surface copper ores were worked in Cyprus by the Phœnicians and by the Romans. From systematic drilling over some old mines at Lymni, near Paphos, it was estimated in 1910 that there were 2¼ million tons of ore containing 1¼% copper and 19½% sulphur. The Cyprus Mines Corporation (American) has recently been developing on a large scale mines at Katydata, near the new railway extension, and at Foucassa, near Skouriotissa. From the latter 2,000 tons of cupriferous pyrite were mined in 1920. Copper with a small quantity of cobalt is found in the Troödos Mts. amongst igneous rocks rich in magnesia [52/No. 65, p. 47] [53/p. 20].

India

According to Panchanan Neogi [54], there was a considerable copper industry in ancient India. The metallurgy of copper was "indigenous" to the country, in many parts of which are to be found abandoned mines and slag heaps. There never was a bronze age in India, but there was a copper age in the north at about 1000 B.C. There was a considerable output

of metal in the third and fourth centuries B.C. and colossal objects of copper were made, some of them still standing.

Many occurrences of copper are known in Northern India, commonly in pre-Cambrian rocks of Dharwar age—gneisses and schists or phillites and limestones; also at intervals along the mountain regions, which border India to the west, north and east, including Baluchistan and Afghanistan, deposits occurring from Kashmir and Kangra through Garhwal and Sikkim to Bhutan and Assam, and in several parts of Burma. The ores are chalcopyrite, tetrahedrite, malachite and bornite, and are met with in veins and breccias.

Native copper has lately been found in Assam in the Sylhet trap, south of Cherrapungi. It also occurs in Deccan trap near Kolapurtown, Bombay Presidency [56/1922, 14. pt. 1, p. 20].

The Cape Copper Co., Ltd., owns the Rakha Hills (Rajdoha) copper mine at Surda, in the province of Chota Nagpur, and also prospecting rights over 30 miles in the adjoining Singhbhum district. The mine, an ancient one, which has been considerably developed, shows an extensive belt of cupriferous schist in "blanket" formation, and contains 320,000 tons of ore reserves with 4% copper. It is equipped with a 300 ton flotation plant, a blast furnace and a converter. During 1920, an amount of 35,540 tons 3·57% copper ore was treated for a production of 512 tons of refined copper [55/1920, p. 171].

The Bawdwin mine, described on page 61 of the Imperial Institute monograph on *Lead Ores*, contains in its ore reserves, according to the 1920 report of the Burma Corporation, Ltd. (India), 335,000 tons of cupriferous ore with copper, 11%; lead, 12·8%; zinc, 7·7%; silver, 23·2 oz. per ton.

Recent total outputs of copper ore in India, all of which came from the Rakha Hills mine, were as follow:

	1916.	1917.	1918.	1919.	1920.
Ore (long tons) . .	4,135	20,108	3,619	32,750	28,167
Value (£)[1] . . .	6,202	30,162	4,053	52,416	42,250

[56/pt. 3].

[1] At current exchange.

Palestine

Copper ores, principally malachite, occur in Palestine in Cambrian sandstones, and have been worked in the past at Wadi Ruweibeh and other places south of the Dead Sea. Smelting was carried on at Fīnān, in Wadi Fedán. It is doubtful if the deposits would repay exploitation at present. [57/No. 1215, p. 96].

AFRICA

Anglo-Egyptian Sudan

Copper ore is mined and smelted by natives at Hofrah el-Nahas, about one mile west of the River Umbelasha, a tributary of the Bahr el-Arab, on the boundary between the provinces of Darfur and Bahr el-Ghazal of Anglo-Egyptian Sudan. The workings are a large number of shallow pits within an area of half a square mile, and mining has been carried on by natives probably for centuries. Copper rings up to 12 lb. in weight are produced as objects of barter [52/No. 98, p. 131].

Kenya Colony

A quartz lode, carrying copper, and striking N.W. to S.E., was discovered in 1907, extending from the foot of the Kiulu Mt. through the Tsavo Valley of Kenya Colony. Assays showed 30% copper, with some gold [58].

In the West Kenya district, near the old Somali road from Rumuruti to Archer's Post, copper is said to occur in lodes, and in the Seyidie Province, 25 miles west of the port of Kilifi, there are said to be large deposits of copper with silver, lead and barytes [59].

Northern Rhodesia

The copper deposits of Northern Rhodesia occur in the equivalent of the Dolomitic series of the Transvaal [53/p. 31].

The Kafue Copper mines, 200 miles west of Broken Hill, produced to 1920 a total of 6,805 tons of copper. The ore-bodies are irregular, rich masses of oxide ores and bornite occurring in dolomite.

The Kasanshi mine on the Belgian Congo border is about 12 miles from the Congo-Zambesi divide and is controlled by Tanganyika Concessions, Ltd. It is an ancient working, and its copper deposits are beds of sandstone from 1 to 10 ft. thick, impregnated with copper, mainly as malachite and chrysocolla, and resting on limestone and schist. The mine is equipped with a small blast furnace, with which charcoal fuel is used. Up to May, 1913, there was a production of 5,200 short tons of copper.

The Bwana M'Kubwa Copper Mining Co., Ltd., holds the mine of the same name of 675 acres, and other properties near by, with a total area of 43,000 acres. The mine is north of Broken Hill, on the railway, and 1,476 miles from Beira. The ore is an impregnation of felspathic quartzite. The ores above water-level at 200 ft. are carbonates and silicates, and below, chalcopyrite and bornite. The ore reserves of the Bwana M'Kubwa in June 1916 were estimated to be 23,000 tons of 10% ore and 3,000,000 tons of 4½% ore above the 3rd level. Between the 4th (450 ft.) and 6th (650 ft.) levels there are possibly another 1,200,000 tons of low-grade ore. A concentrating plant of 90 tons per day capacity was put into operation in 1913, producing a 40% concentrate. During the year 1917-18, 16,295 tons of ore produced 1,419 tons of concentrate. A novel development of the Minerals Separation process has recently been tried upon the oxidized ores with a 100 ton per day unit, and an 85 to 90% extraction can be obtained with it.

The M'Kana group of ore-bodies, 30 miles west of the Bwana M'Kubwa, is being developed. Various types of lode present include fissure veins and impregnations in felspathic sandstones, slates, conglomerates, sericite and mica-schists. In the last the oxidized ores are malachite, chrysocolla and melaconite with much oxide of manganese, derived from an iron-manganese variety of mica. Primary bornite will probably be the main ore below. The principal lode, proved for a length of 5,300 ft., is from 20 to 100 ft. wide, and contains from 3 to 6% copper. Another lode, 50 to 80 ft. wide and containing from 7 to 11% copper is 1,800 ft. long. It is reported that 3,000,000 tons of ore could be mined per 100 ft. of depth.

A fissure lode in gneiss, near Susaka, 4 ft. thick and containing 9% copper, has been proved 1,200 ft. in length and is being developed [60].

Recent productions of copper from Northern Rhodesia were as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Short tons	855	197	1,298	2,019	888	204	146	220

[61].

Southern Rhodesia

The most important copper-bearing district of Southern Rhodesia is the Sabi, in which the principal mine is the Falcon; there are other much less important deposits elsewhere.

The Falcon mine of the Falcon Mines, Ltd., is 60 miles N.E. of Gwelo. It has an area of 619 acres, and the company also holds the Iron Mine Hill of 349 acres, 27 miles away, as a source of iron ore for fluxing. The ore is auriferous, and the ore-bodies, which are of the nature of an impregnation and are in schists considered to be of Waterberg age, are large, up to 50 ft. wide at the 9th level.

The treatment plant of 15,000 tons per month capacity consists of a milling and flotation plant and a smelter equipment with 12 hemispherical blast-roasting pots, two 300 ton blast furnaces and 12 converters of 15 tons capacity. The blister copper is refined in New York. During the 12 months to June, 1921, 184,500 tons of ore were treated for 3,086 short tons of copper. The ore yields, besides copper, about 4 dwt. gold per ton with silver.

The ore reserves in June 1921 were 469,000 tons [70/1922, p. 209], but they are decreasing both in quantity and value.

Recent productions of copper from Southern Rhodesia were as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Short tons	1,011	3,517	3,521	3,911	3,254	3,012	3,108	3,079

[61].

Tanganyika Territory

Copper minerals are found, in quartz at Ujiji, Kigoma district; at Masasi, Lindi hinterland; and in the Langenburg district [215].

Uganda

Roccati reports the existence in Uganda of chalcopyrite ore on Mt. Baker, and of abundance of malachite, tetrahedrite, and chalcopyrite ores on Mt. Stanley. Chalcopyrite has been found near one of the tributary streams of the Ruwenzori.

Only traces of copper have so far been discovered in the more accessible parts of the country: if copper ores are found later in quantity it will probably be established that they are in connection with the pre-argillite rocks in parts of the Eastern Province.

Certain gozzans show copper staining, and copper ores may be found below them [62].

Union of South Africa

Copper is found in the Union of South Africa chiefly in the sulpho-ores, chalcopyrite and bornite.

The principal producer is the Messina mine of the Messina (Transvaal) Development Co., Ltd., in the Northern Transvaal, close to the border of Southern Rhodesia. The ore-body is large and occurs in a well-defined, steeply-dipping fissure of varied width in granitic gneiss. Near the surface the ore is chiefly chalcocite, which changes in depth to bornite and chalcopyrite. The company has milling, concentrating and smelting plant of 250 tons per day capacity, and sends to England matte, concentrate and rich ore (45 to 55% copper). The following are recent productions of copper at Messina:

	1916–17.	1917–18.	1918–19.	1919–20.	1920–21.
Short tons . .	5,111	3,537	2,703	2,100	nil

At the end of June 1921 there were 566,000 tons of reserves of 3·25% ore.

In Cape Province the chief deposits, which are in Namaqualand, Western Province, have been worked since 1852, but are now nearly exhausted. One company, the Namaqua Copper Co., Ltd., owns the Tweefontein and other mines at Concordia. Irregular deposits of chalcopyrite occur as magmatic segre-

gations from basic igneous rocks and granite The company has flotation, briquetting and other plant, and a smelter. In 1917 there was a production of 1,368 tons of copper from 21 355 tons of ore. Owing to suspension of shipments from South Africa smelting was stopped in May 1918. In December 1920 there were 63 000 tons of reserves of 7·1% ore and 18,000 tons of 6% tailing.

The Cape Copper Co., Ltd., owns several mines at O'okiep, of which the most important are the O okiep and Nababeep. These have large ore-bodies of magmatic origin similar to those at Concordia, the ore consisting mainly of chalcopyrite, with small amounts of bornite and chalcocite. There are smelting plants on both mines, 28.079 tons of ore being smelted in 1918. The Nababeep mine has 90.000 tons of 4·6% ore. The company owns a 90-mile railway to Port Nolloth, and ships its rich ore and matte to Briton Ferry smelter in South Wales. All operations, except those of prospecting by drilling, were stopped in May 1919.

There are copper deposits elsewhere in Cape Province: at Turnstream, in the Cathcart district, but not of proved value; at Beaufort West; and at Insizwa, in the Mt. Ayliff district on the boundary of East Griqualand and Pondoland. At the last the deposit also contains nickel, cobalt, gold, platinum, and silver. It was explored from 1911 to 1914, and also recently. The deposit is similar to that at Sudbury, Ontario, and is thought to be due also to magmatic differentiation.

The massive cupriferous pyrite of the New Areachap mine, at Gordonia, Cape Province, is used for acid-making. Other copper deposits in South Africa are found at Marks Drift on the Orange River; in Zululand; and at the Albert mine, N.E. of Bronkhorst Spruit, Transvaal, the fissure vein of which contains silver also. The majority of these mines are only being developed.

Recent shipments of copper (metal content) contained in matte and rich ore, from the Union of South Africa were as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Short tons. .	12,671	12,117	11,628	8,930	5,318	3,943	1,195	24

South-West Africa

The most important copper-producing district of the protectorate of South-West Africa is the Otavi, in which is a group of mines originally controlled by the South-West Africa Co., Ltd., and afterwards by the Otavi Mines and Railway Co. (German). The principal mine is the Tsumeb, which is 12 miles from Lake Otjikoto and 354 miles by rail from Swakopmund. Its ore-bodies are steeply-dipping lenticular veins with a sandstone hanging-wall and a dolomite foot-wall. The ore is brecciated with inclusions of the walls and is complex, containing various proportions of argentiferous galena and chalcocite, accompanied by blende, pyrite, enargite, and, on the lowest level of the mine, by chalcopyrite. It is apparently of metasomatic origin. The other deposits of the company are at Guchab, Great Otavi, Little Otavi and Asis, and are huge masses in limestone. The company holds mining rights over 1,000 sq. miles leased to the Otavi Exploring Syndicate, Ltd., and 500 sq. miles of freehold at Otavi.

Before the war, outputs of copper ore in metric tons of the Otavi Co. were as follow:

	1911-12.	1912-13.	1913-14.
Tsumeb mine	38,200	52,200	68,200
Other mines	3,000	1,900	1,900
Total	41,200	54,100	70,100

The metallic contents of the above are not known, but it has been stated that the ore of the Tsumeb mine, exported in 1913–14, contained: copper, 13%; lead 25%; silver, 7·7 oz. per ton. Copper ore was being mined before the war by two companies at Otjizongati, N.E. of Windhuk, where there is at surface chalcocite ore followed by chalcopyrite and pyrite in depth, in lenticular quartz veins in gneiss and mica-schist: the mine was closed down at the time of the British occupation. Similar deposits occur in the Hope, Naramas, Gorap and Matchless mines.

Copper ore occurs at Sinclair, N.E. of Luderitzbucht; at

Neuras, S.W. of Rehoboth; at Spitzkopf, N.E. of Rehoboth; at Duruchous; at Gaidip, on the Orange River, east of Raman's Drift, and at Khan Valley, Swakopmund district. In the last the Khan mine contains a pegmatite vein, in schist, 1,300 ft. long, 750 ft. deep and 6½ ft. wide, the average copper content being 7½%. The ore minerals are principally bornite with chalcopyrite and chalcocite. The mine, recently opened up, had in 1914 a mill treating 50 tons of ore per day and producing 60 to 70% concentrate, but it was closed down in 1918 [64] [65].

Exports of ore in long tons made by the two principal operating companies in recent years were:

	1918.	1919.	1920.
Otavi Mines and Railway Co. .	7,358[1]	6,400	30,511
Otavi Exploring Syndicate .	100[2]	206	80
	8,458	6,606	30,591

[1] Assay value 12–33% copper.
[2] Assay value 43·5% copper.

At the present time (1922) the Tsumeb is the only mine producing copper ore in the Protectorate. Its output for the financial year ended March 31, 1922, was about 85,000 tons of ore. This resulted in the shipment of 36,820 tons of ore and concentrate containing, on an average, 13·5% copper, 29·3% lead, and 10·5 oz. silver per ton. Small outputs from the Guchab and Asis mines are included. At the company's smelter were produced in addition 2,894 tons of copper matte containing an average of 49·3% copper, 20·3% lead, and 27·3 oz. silver per ton.

NORTH AMERICA

CANADA

The Bruce copper mines in Ontario were opened in 1846, but are still undeveloped. Copper mining proper began in the Dominion with the working of the Sudbury deposits in 1886.

Largely owing to the opening up of large copper deposits n British Columbia, the principal producing province, the)utput of copper of the Dominion has increased very much in the last few years. During the war it was abnormally high, as will be seen from the following table, which includes the totals of home-treated and exported ores:

Outputs of Copper of Canada

Year.	Short tons	Year	Short tons.
1909	26,246	1916	58,575
1910	27,846	1917	54,613
1911	27,824	1918	59,384
1912	38,916	1919	37,562
1913	38,488	1920	40,800
1914	37,867	1921	26,731
1915	59,397		

[66]

During the period 1914–21 the percentages of the total Dominion production made by the provinces were: British Columbia, 56·4; Ontario, 37·2; Quebec, 3·9; Yukon, 1·1. Since 1917 Manitoba has been a producer, with an output in the period 1917–21 of 2·3% of the total.

The smelting industry is now helped in Canada by a bounty of $38 per ton on home-produced metallic copper.

Alberta

A small chalcopyrite deposit was recently worked in Alberta on the south side of Bow Valley, between Banff and Lake Louise [67/p. 440].

British Columbia

The production of copper in British Columbia dates from 1894. The most important deposits of ore are to be found in the Rocky Mts., but the coastal region is also noteworthy for its production. Copper mining is now a firmly-established industry in the province. Recent annual productions of copper were as follow:

	Short tons.		Short tons.
1913	23,230	1918	30,741
1914	22,505	1919	21,230
1915	28,459	1920	22,444
1916	31,689	1921	19,518
1917	29,504		

[68]

The 1918 to 1921 outputs in short tons, as produced by the various districts, were as follow:

	1918.	1919.	1920.	1921.
Skeena division . .	15,095	10,206	13,077	17,408
Southern Coast district .	9,237	8,531	8,156	728
Boundary-Yale district .	5,238	1,918	653	216
Trail Creek division . .	828	556	557	1,139
All others . . .	343	19	1	27
	30,741	21,230	22,444	19,518

The totals represent 52·57, 55 and 73% of the total outputs of Canada, respectively, for the above years. The output of the Omineca division included in the last section was almost nil in 1919, as its principal mine, the Rocher Déboulé, was closed down in 1918.

In the Skeena district the Gribbell Island mine has not been operated since 1906 owing to lack of funds. On Princess Royal Island is a gold-copper mine and hydro-electric power plant, owned by the Belmont Surf Inlet Mines, Ltd., which has been developed by 16,000 ft. of tunnels. The reserves on January 1, 1921, were reported as 234,000 tons of 11 dwt. ore. The mine is equipped with a 300-ton milling, wet-concentrating and flotation plant, which has shown that table concentration will save a half, and flotation the other half, of the recoverable gold content, whilst the combined treatment will save 94% of the total gold and 96% of the copper [9/p. 1519] [10/p. 1532]. In 1920 the company's production was 44,051 oz. gold, 20,104 oz. silver and 343 short tons of copper from 108,082 tons of ore. The hydro-electric power plant delivers current at a cost of 0·23 cent. per kw.-hour.

An unusual copper-lead deposit occurs near Legate Creek, 15 miles east of Pacific on the Skeena River. The formation consists of a series of bedded volcanic rocks (Hazelton—probably Jurassic), intruded by dykes and sills of quartz-porphyry. The ore-body, which strikes N.-S. and dips E. 35°, parallel to the country-rock, is of the replacement type, with massive andesite on the hanging-wall and tuff agglomerate on the foot-wall. The upper portion, from 8 in. to 5 ft. in thickness, is

hard, being silicified and carrying disseminated chalcopyrite (secondary) with some bornite, galena and pyrite. It assays from $6·50 to $60 per ton, which values are largely accounted for by the copper content. The lower portion, from a few inches to 8 ft. in thickness, is soft, and consists of broken decomposed rock and clay (*flucan*), containing rounded masses of a mixture of the above ores. Below there is a well-defined foot-wall, which is slickensided. There has been folding of the foot-wall, with consequent brecciation of the lower soft portion. The masses of sulphide lie chiefly in depressions in the drag-folds of the foot-wall. About 125 tons of ore, shipped in 1916–17 from these depressions, assayed: Copper, 18%; lead, 30%; silver, 18 oz. per ton [69].

The Granby Consolidated Mining, Smelting and Power Co., Ltd., controls the Granby group of mines at Phœnix, Boundary district; the Hidden Creek mine and Bonanza group at Granby Bay, Observatory Inlet; smelters at Grand Forks and at Anyox; also mines in Washington and in Alaska. At Granby Bay the ores are massive sulphides and are in replacement shoots near the centre of a large mass of argillites and greenstones.

The Hidden Creek mine, at Granby Bay, is probably the largest copper mine in the British Empire. The ore occurs as a solid mass of pyrite and chalcopyrite, or, mixed with country rock in shear zones, in crushed and schistose argillite. The rocks are part of the cover of the great granite mass forming the coastal range. There are two deposits: one 25 to 40 ft. wide, traced for 1,400 ft. and said to average 6% copper; the other, 100 ft. wide and of unknown length. Diamond-drill development shows ore 300 ft. below sea-level, or 1,200 ft. below the outcrop. At the end of June 1919 the reserves were estimated at 11,222,000 tons containing 2·24% copper.

The Bonanza group, adjacent, contains 904,000 tons of 1·61% ore.

The Anyox Smelter on Observatory Inlet, treating ores from the two mines above, consists of 4 furnaces, has a daily capacity of from 2,000 to 2,500 tons, and is the largest pyritic smelter in the world.

During 1920, from the Anyox mines 802,667 short tons of ore were smelted, yielding 12,702 short tons of fine copper, 381,742 oz. silver, and 7,615 oz. gold.

On Queen Charlotte Island the Ikeda Mines, Ltd., holds 2,100 acres in several groups on Ikeda Bay at the south of Moresby Island. The Lily group contains several veins up to 8 ft. wide, and a principal vein from 5 to 30 ft. in width, which has been developed for 1,000 ft. along the strike and 300 ft. in depth. In the latter, the ore shoot, up to 20 ft. in width, carries lenses of chalcopyrite with an average copper content of 2·5% [10/p. 1559]. The output in 1920 was 141 tons of ore, yielding 11 tons copper, 27 oz. gold, and 305 oz. silver. The mine requires a 50-ton mill to treat the second class ore, of which there are 7,000 to 8,000 tons in sight. The mines closed down in the summer of 1920 till fresh capital could be raised.

In the Hazelton or Omineca district chalcopyrite ores occur in fissure replacement or shear-zone replacement veins in the Hazelton series. Gold usually accompanies the copper. The Amargosa mine of 300 acres, 5 miles from Hazelton, is stated to cover 3,000 ft. on the strike of a series of veins from 4 to 10 ft. wide, carrying copper-silver-gold ore. The Highland Boy of 400 acres on Rocher Déboulé Mt. contains extensions of the Rocher Déboulé veins, two of which have been intersected by tunnelling. The veins are of fissure type, following intrusive dykes of porphyry in granite. Samples from veins 18 in. to 5 ft. wide assayed from 1·5 to 5·7% copper with low silver and gold contents. The Cassiar Crown mine of 250 acres on Grouse Mountain, prospected by surface workings and by a 750 ft. tunnel, which has reached the mineralized area 240 ft. below the surface, is claimed to contain an average of 7% copper and 3 dwt. gold per ton. The Delta and Chicago mines, adjoining the Rocher Déboulé on the east, in September 1917 were said to have a 6 ft. lode with 5½% copper. The Golden Wonder on Rocher Déboulé Mt., 1 mile from Hazelton, shows a 2½ ft. vein of chalcopyrite ore assaying 8% copper. The Great Ohio copper mine, adjoining the Butte Rocher Déboulé mine, developed by a 355 ft. tunnel, open cuts and drifts, has shown a fissure vein in granodiorite, which has been traced on

the surface for 700 ft. The main ore-body, 4 ft. wide, gave assays of 22·5% lead, 9·5% copper, 8·4% zinc, 134 oz. silver, and 0·8 dwt. gold per ton. The Rocher Déboulé of 325 acres with 50 acres mill site, 9 miles from the Trunk railroad, has been developed by an 800 ft. tunnel and a shaft. Five ore-shoots of average width 5½ ft., 3,000 ft. long, have been proved to an average depth of 150 ft. The ore occurs in E. and W. fissure veins dipping 60°. It is claimed that the tunnel and shaft developed 25,000 tons of 15% ore, with 5 oz. silver and 1½ dwt. gold per ton. The copper occurs principally as chalcopyrite and bornite. The 5 ft. of 10% ore opened up on No. 1 vein on the 1,000 ft. level is being explored by a 3,000 ft. tunnel at 1,200 ft. depth.

In 1916 the copper produced was 625 short tons from 10,000 tons of ore. The Silvered-Copper mine of 300 acres in Hunter Basin, Omineca district, is about 15 miles from the railway at Telkwa. Its ores are bornite and chalcocite, in fissure veins in diorite. Trial shipments of ore to a smelter in 1914 averaged over 100 oz. silver per ton and 5% copper. The property, idle since 1915, is apparently valuable, but the company is out of funds [9/p. 1503]. Only 8 short tons of copper were produced in the Omineca division in 1920.

The Le Roi No. 2, Ltd., owning the Josie No. 1, and Annie mines, all on Red Mt., has also other claims in the same district and in the Ymir district. On the Josie there are 5 main veins of chalcopyrite ore with pyrite and pyrrhotite, averaging 2·25% copper, 0·45 oz. gold and 1 oz. silver per ton. Three of these veins pass through the Giant-California mine, where the ore is of 0·48% grade, with 0·14 oz. gold and 0·25 oz. silver per ton. The company owns a 50 ton wet-concentrating plant, which produces concentrate averaging 0·59% copper, 0·83 oz. silver, and 1·02 oz. gold per ton [9/p. 1533]. In 1917–18 the output of 15,317 tons of ore yielded 115 tons of copper, 10,560 oz. gold and 8,261 oz. silver [70/1921, p. 321].

In the Le Roi-Centre Star group of mines of the Consolidated Mining and Smelting Co. of Canada, in the Trail Creek or Rossland district, the volcanic country rock of Palæozoic age has been intruded by an elongated mass of monzonite-porphyry, which, in turn, has been intruded by a number of N. and S.

basalt dykes, some of the larger cutting off the veins completely. The ore-bodies are nearly parallel with the dykes, and occur mainly at the point of their intersections with the veins. The ore-shoots vary in size from 3 to 50 ft. wide, and from 50 to 600 ft long, and are wider at the points of intersection. In places there are local enrichments.

The ore is a highly-auriferous chalcopyrite containing silver, associated with pyrite and pyrrhotite, and contains from 0·5 to 2% copper with from 8 to 20 dwt. gold per ton.

The more important mines of the group are on the southern slope of the Red Mountain, at Rossland, and are the Centre Star, and Le Roi. They are practically one mine and are connected and developed by over 56 miles of workings. All mining operations are carried on with the aid of hydro-electric power, brought from the Bonnington Falls plant, 35 miles away [9/p. 1530].

The Trail Smelter of the same company, near the international boundary, is at present the only one in the world producing electrolytically refined copper, gold, lead, silver and zinc at one plant; it also makes sulphuric acid, hydrofluosilicic acid, bluestone (copper sulphate), and manganese dioxide. The copper reduction plant consists of 4 blast furnaces, two 12 ft. basic-lined converters, a reverberatory for casting copper and an electrolytic copper refinery. The company's recent copper outputs were for the years 1915-19: 2,653; 2,223; 3,702; 3,091 and 3,467 short tons, respectively. The electrolytic refinery is the only one in British Columbia, and can produce 50 tons per day [10/p. 1538].

In the Phœnix mines of the Granby Consolidated Co., near Grand Forks, the ore-bodies are replacements of limestone containing finely-divided chalcopyrite. The main ore-body is in the Old Ironside-Knob Hill and was opened by an immense pit, 400 ft. by 1,000 ft., but recent extraction was mainly through tunnels. The ore remaining is now of low grade, yielding less than 15 lb. copper and 84 cents. gold and silver per ton. The mines except the Ironsides are almost exhausted. The ore was smelted at Grand Forks, 24 miles away. The mines and smelter were closed down early in 1919.

In the Osoyoos district, Yale, at the Olalla mine at Olalla,

and the Dividend mines 17 miles away, now idle, there are contact deposits of copper between diorite and felsite, the ore-bodies being in both, but mainly in the felsite. It is claimed that the vein being developed carries from 1·5 to 5% copper, with a little silver and gold. The mines are to be developed by the Yale Development and Construction Co.

In the Nicola district at Quilchena are the Tubal Cain, King William and Joshua mines of the Donohue Mines, Ltd., containing copper, lead, zinc, silver and gold ores. The veins have been followed to a depth of 400 ft. [9/p. 1509].

In the Similikameen district the Canada Copper Corporation, Ltd., owns 3,006 acres on Copper Mt. (altitude 4,200 ft.). The mountain is 9½ miles south of Princeton. The ore-bodies occurring in monzonite-porphyry and granodiorite, which themselves have been intruded by light-coloured porphyry dykes, contain finely disseminated chalcopyrite, bornite and pyrite. There are only slight evidences of secondary enrichment. Extensive diamond drilling has, according to report, so far disclosed 10,000,000 tons of actual and 2,000,000 tons of probable ore containing 1·74% copper and small amounts of gold and silver. The ore has been tested by a 40-ton flotation plant, which, in the absence of oxidized ores, promises a 90% extraction, the production of 25% concentrate with a concentration ratio of 17 to 1 having been maintained. The mill, completed at the end of 1919, is rated at 2,000 tons per day [10/p. 1537].

The mine and mill were closed in 1920 owing to the impossibility of operating successfully with copper at 13 cents per pound.

In the Kamloops district the Kamloops Copper Co. is developing the Iron Mask and Erin mines. The main ore-body of the former is lenticular in shape, of 28 ft. average width, with a copper content of 5% and small amounts of gold and silver. The ore is difficult to concentrate owing to its chloritic and quartz-orthoclase gangue. Excellent ore has been opened up in the Erin mine. The two mines, according to report, have reserves already developed of 1,800,000 tons of 2½% ore, with much low-grade ore in addition which could be treated by flotation [9/p. 1504].

In the Yale district the claims of the Oregon and British Columbia Mining and Development Co., Ltd., have been developed by a 176 ft. tunnel, which has intersected 40 ft. of ore carrying chalcopyrite and bornite. Development has been temporarily suspended [10/p. 1570].

At Howe Sound, in the Vancouver division (Mainland), is the Britannia mine, which, with timber concessions and beach lots, covers an area of 25,000 acres. It is controlled by the Howe Sound Co. of New York, and is one of the largest copper mines in the British Empire. The ore-bodies consist of nearly parallel lenses of chalcopyrite and pyrite in schist, and large masses of siliceous material, with chalcopyrite and pyrite disseminations. The ore-bodies in 100 acres only have so far been developed.

At the end of 1920, broken ore in the stopes, according to report, amounted to 1,687,000 tons of 3% copper, and the reserves in place amounted to 4,952,000 tons, averaging 1·9% copper. The four units of the new mill, to handle 2,500 a day, and consisting of jigs, coarse and fine crushing and flotation plants, are in operation. In 1920, 8,101 short tons of copper with 6,013 oz. gold and 90,672 oz. silver were produced from 697,897 tons of ore. The concentrating part of the mill was burned down early in 1921. It has been rebuilt.

The Sunloch copper deposit, discovered a few years ago, is near Jordan River, Vancouver Island. The ore is chalcopyrite, finely disseminated or in the form of a network of small filmy veinlets, in an altered basalt near a mass or dyke of gabbro (Tertiary). The sulphides, chalcopyrite, pyrrhotite and pyrite, are sporadic in their occurrence and irregularly distributed. At the end of 1918, the reserves were estimated to be from 100,000 to 150,000 tons, assaying from 3 to 5% copper [71].

Manitoba

At Schist Lake, N.W. of The Pas in Northern Manitoba, is the Mandy mine. The deposit consists of a lens, elliptical in plan, lying in chlorite schist, which is interbanded with massive greenstone. The mineralization is very similar to that of the Flin Flon ore-body, described below, but the various sul-

phides are less intimately mixed, and the percentage of chalcopyrite is higher [72/p. 164].

In 1917, 3,500 tons of ore, with 17% copper, were shipped to the Trail smelter. In 1918 the shipments amounted to 6,300 tons, and about 20,000 tons of 20% ore had been developed. In 1920, 7,535 tons of ore were shipped.

The Flin Flon ore-body, discovered in 1915 at the S.E. end of Flin Flon Lake, lies in amygdaloidal greenstones, associated with quartz porphyries, and with later lamprophyric dykes. The ore-body is formed of more or less independent lenses separated by greenstone, has a known length of 2,593 ft., and has been proved by diamond drilling to a depth of 900 ft. over a length of 1,000 ft. The width varies from 35 to 400 ft. The total tonnage, according to report, has been calculated to be 16,000,000. The minerals in order of importance are pyrite, blende and chalcopyrite. Gold and silver appear to be associated with the pyrite. Solid sulphides occur in the centre and towards the hanging-wall, whilst on the foot-wall there is a considerable width of disseminated ore. The whole ore body contains approximately: Copper, 1·9%; zinc, 3·8%; silver, 1½ oz., and gold, $1·40 per ton. The deposit has been formed by replacement which has followed intense shearing, associated in places with silicification. In September 1920 the sinking of two shafts - about 500 ft. apart—was being continued to the 300-ft. level [73]. About 25,000 tons were mined in 1919, and about 36,000 tons in 1920. Over 78% of the 1920 production was in blister copper and in matte.

At Phantom Lake, a short distance west of Schist Lake, there is a variety of minerals, including pyrite, chalcopyrite, and molybdenite, whilst assays have shown the existence of nickel [74].

Discoveries of copper sulphides at Lake Athapapuskow were made in 1918. Exploratory workings on the border of the lake show chalcopyrite and bornite, and assays indicate 3 to 4% copper. The same ore is found farther east, at the extreme end of the lake. E. L. Bruce considers that these deposits cannot be worked under present conditions [75].

Near the mouth of the Pine Root River, the Chica claim,

one of the earliest discoveries in the Schist Lake, is being tested with a diamond drill. In addition to copper, the assays show gold and silver. The deposit consists of a sheared and faulted zone mineralized by pyrite and a little chalcopyrite [72/p. 2].

A very large body of sulphides, consisting of pyrite and nickel-bearing pyrrhotite, was located in 1915 and later years on Brunne and Copper lakes, which lie about 10 miles N.E. of Athapapuskow. It is said to be very wide and to be traceable for about 5 miles [74].

Recently the Canadian Government suspended for another period of ten years the royalty tax on copper ore. This should encourage the development of the Schist Lake district. All the formations are of Pre-Cambrian age. Owing to the state of the market, to transport difficulties, and to high freight rates, there was no production of copper in Manitoba in 1921.

New Brunswick

The Vernon Copper mine, on the north shore of the Bay of Fundy, developed by the Eastern Canadian Copper Corporation, Ltd., is on a hill 550 ft. high. Dolerite dykes cut through the country rocks of diorites, schists, and slates. The property has been developed by 7 tunnels from 50 to 170 ft. long, which have disclosed a quartz-calcite vein, containing bornite and chalcopyrite.

The Intercolonial Copper Co. is developing a blanket vein carrying carbonate and sulphide ores, said to contain from 3 to 4% copper. The company owns a treatment plant, which consists of a 200-ton concentrator, a leaching plant and an electrolytic refinery. The plant proved unsatisfactory [9/p. 1543].

North-West Territories

The existence of copper in the northern regions of the North-West Territories has been known for over 200 years from the reports of Esquimaux and Indians. In 1771 the position of the Coppermine River deposit was confirmed by Samuel Hearne, who visited the district with some Indians. In 1821 Franklin visited this deposit and also reported the presence of copper on

the islands in Bathurst Inlet. In 1835 James Ross found trap rocks on the east coast of Boothia in latitude 70° N., and noted copper ore near Agnew River. The Esquimaux have reported large masses of native float copper ore on the shores of Princess Royal Islands and Prince of Wales Island, and also on Victoria Island at a point 40 miles N.E. of the head of Prince Albert Sound. In 1917 a police patrol found native copper in rocks about 60 miles east of Bathurst Inlet [76/p. 396].

Up to 1911 nearly all observations had been made by untrained observers and were often very vague and unreliable, but in that year an expedition, organized by the late James Douglas, and under the leadership of George M. Douglas, made a reconnaissance of the Coppermine River district, staying one month on the spot. James Douglas described the results obtained at the annual meeting of the Canadian Mining Institute in 1913, and in the preface to the book, *Forlorn Lands*, written by the leader, said of the Coppermine River that " the region within which copper ore may possibly be found covers nearly 10,000 sq. miles."

The Coppermine River enters the Arctic Ocean at the head of Coronation Gulf, one of the most remote and least accessible places in the world. The copper deposits are in a series of flows of basaltic lava with occasional interbedded conglomerates and sandstones. They occur in a belt, 16 miles wide, 40 miles long, known as the " Copper Mountains," which crosses the Coppermine River at 40 miles from its mouth, in a direction slightly north of west. The flows and sediments dip N. 12°, so that the edges are exposed and are covered by younger rocks to the north. The Douglas party reported native copper in place at Copper Creek, in 30 ft. of exposed basalt, the copper being either in amygdules or in small shots or flakes; and at Burnt Creek also similar copper was reported in 51 ft. of basalt and in pebbles in 25 ft. of conglomerate. In the massive rock the assays varied from a trace to 1 %, and in the amygdaloidal rock from nil to 7 %. Further extensive prospecting was warranted.

The Bathurst Inlet deposits were reported on by J. J. O'Neil of the Canadian Arctic Expedition in 1915–16 [77] [78]. The rocks are apparently distinct from those of the Coppermine

River and the deposits are found, roughly, in an oval, whose greatest length is 50 miles in a N.W.-S.E. direction and whose greatest width is 25 miles. The area includes 150 islands, of all sizes up to several sq. miles each; part of the western mainland, namely Bank's Peninsula; and a strip along the coast, 5 or 6 miles broad, extending from Arctic Sound to Moore Bay. The formation is a series of basic lava flows with a few thin beds of sediment. Native copper was found practically everywhere, and its distribution in the flow, where found, was remarkably uniform. It usually occurs in a disseminated form in the ground-mass of the basalts; in amygdaloidal form in gas cavities near the surface of the basalts; or as vein copper in fissures. Prospecting would be confined to finding places where the amygdaloidal and vein classes of copper are found in concentrated form. On the borders of the area, on the south and west sides, a series of dolomites underlie the basalts, and in three different places bornite was seen to have replaced the dolomite for several feet below the contact. J. J. O'Neill emphasizes the importance of examining these sulphide deposits on Bathurst Inlet, but also of looking for deposits of sulphides, which might occur in the limestones of the Coppermine River area. He suggested that, although the Bathurst Inlet deposits are on tide water and could be reached by sea, prospecting expeditions should be taken there by hydroplanes starting from Great Slave Lake, which is at the head of the railway, using intermediate lakes as alighting places. This scheme would allow of from five to six months' prospecting per year, and avoid loss of time through wintering [79]. This method of prospecting has already been adopted.

After the return of its Arctic Expedition, the Government of Canada, in December 1918, decided to withdraw from staking all Canada lying north of 65° N., and between 105° and 116° W. longitude " in order that the deposit of native copper reported to exist in that region may be thoroughly examined " [76].

Willet G. Miller points out that Canada has an area of 3,750,000 sq. miles, and in about two-thirds of this area there are pre-Cambrian rocks, and wherever these occur the conditions are similar to those of Northern Ontario, where extensive

deposits containing gold, silver, nickel and copper are known. He considers the northern regions of Canada to be the most attractive unprospected area in the world.

The rocks of the Coppermine River are much like those at Michigan, and extend very close to the west shore of Hudson's Bay. The country here would be easier to prospect than Ontario, being much more open. The east coast of Hudson's Bay has been very little prospected and is a promising field for investigation.

The Canadian Government has nearly finished a railway to Port Nelson, which would be a suitable base from which to prospect both the east and west shores of Hudson's Bay [80].

Specimens of copper sulphides, chiefly chalcocite, have been found between Great Slave and Great Bear lakes, but no detailed information is available [67].

Nova Scotia

The old Coxheath mine, 10 miles from Sydney, Cape Breton, of the Cape Breton Copper Co., Ltd., has been idle many years. It contains several cupriferous veins, of which the largest, 10 ft. wide, traverses felsite and diorite, and carries 4·5% chalcopyrite ore with gold and silver. The shaft is 420 ft. deep.

The mine of the Cheticamp Copper Co., Ltd., in Inverness Co., contains 4 ore-bodies, of which 3 have been developed by a 200 ft. shaft and 3 tunnels. It is claimed that 250,000 tons of sulphide ore, averaging from 2·5 to 3·5% copper, 18% lead, 30 oz. silver and from $2 to $30 gold per ton have been developed. The company owns 950 acres of freehold land, besides mill and smelter sites, 200 acres of water frontage, and prospecting rights over 50 sq. miles [10/p. 1591].

Ontario

In Ontario the Allie Island copper mine on the east side of the island of the same name, is 15 miles from Kenora, and 156 acres in area. On it is an outcrop of serpentine, or of chlorite-schist, containing small pellets of native copper. The country rock consists of dolomite, altered traps and

greenstones. The ore-body, which is undeveloped, is said to be ¼ mile long, of maximum width 700 ft., and to contain 1½% copper [9/p. 1547].

The Calumet and Algoma Mining Co. holds 957 acres near Massey, Algoma, in which is a 45-ft. fissure vein, traceable for about 3 miles, containing chalcopyrite ore of medium grade. Some gold is present and occasionally bornite and malachite, when the ore assays from 5 to 25% copper. The mine has been idle for some years.

The Cheney Copper Co., Ltd., holds 700 acres at a point 28 miles from Thessalon and 40 miles east of Sault Ste. Marie. Three parallel veins have been traced by outcrops and by trenching for 1½ miles. The veins varying from 4 to 12 ft. in width, are of quartz mostly, with pockets or lenses of specular iron, pyrite and copper minerals. The property has been explored by a 105 ft. shaft and crosscuts.

At Parry Sound, the Consolidated Copper Co. of Parry Sound holds 1,500 acres of timber and mining country containing copper and mica. The copper ores are contact deposits between slate and quartzite, and also *fahlbands*, or metamorphic rocks heavily impregnated with sulphides, carrying mainly chalcopyrite as the mineral. Of 18 contact deposits 4 have been developed. The fahlbands are stated to show a width of over 1,000 ft. and carry 7 bands of medium grade ore of 200 ft. average width. The ores contain from 1·5 to 12% copper, 3 oz. silver and up to 2 dwt. gold per ton. The principal properties owned are the Spider Lake and the Lefex. The former has a 180 ft. shaft and contains a big ore-body which has been trenched. The latter, opened up by 2 shafts, 90 and 40 ft. deep, is promising.

The Parry Sound Copper Mining Co., Ltd., holds 1,000 acres at Parry Sound, in which are the Wilcox and the McGowan mines. The former has outcroppings of 4 parallel veins, within ¼ mile of width. One vein, 20 ft. wide, and developed by a 145 ft. shaft, has been traced for 1,000 ft., carries bornite, and assays from 2·8 to 11% copper with gold and silver. An opencut 18 ft. deep, disclosed 3% chalcopyrite. The McGowan mine, explored by 4 shafts from 100 to 250 ft. deep, contains bornite, with, occasionally, chalcopyrite ore. A smelter shipment of

240 tons yielded 17% copper and 5 dwt. per ton in gold and silver. The mine is idle at present [9/p. 1554].

The Superior Copper Co., Ltd., holds 800 acres in the district of Algoma. Two fissure veins in granite and chloritic schist, of 10 and 70 ft. average widths, have been traced for 7,000 ft. The quartz veins carry chalcopyrite with some chalcocite, and the ore is estimated to contain 4% copper, 1 oz. silver and ½ dwt. gold per ton. The mine has been developed by 1,233 ft. of tunnelling and shafts, and is equipped with a 50-ton concentrator. It has been idle since 1908.

The Two Lakes Copper Mining Co., Ltd., holds 300 acres of freehold in which are the Robinson and Tupper mines, near Thessalon. Several fissure veins have been discovered in pre-Cambrian rocks—slate, conglomerate and greenstone—of which 3 have been explored. These vary in width from 2 to 10 ft. and assay about 4·5% copper. The property is idle at present.

At Sudbury is the huge basin or boat-shaped deposit of copper-nickel ores, which have been mined since 1886, and of which over 70,000,000 tons have been developed. As the nickel is of greater value than the copper in the ores, the deposit will be described in a subsequent monograph of the Imperial Institute, on *Nickel Ores*.

The average percentage composition of the ores is as follows: Nickel 4·5; copper 2·0; iron 52·0; sulphur 34·0; insoluble 7·0 [42]. The copper occurs as chalcopyrite, and the nickel as pentlandite; magnetite and pyrrhotite are accessory minerals, and there are notable amounts of sperrylite ($PtAs_2$). The sulphides occur massive or disseminated in the country, which is a norite or other hypersthene-bearing rock, and which therefore forms the gangue. The origin of the deposits is still undetermined. In the ores themselves, the ratio of copper to nickel is extremely varied, and, taken against 100 parts of copper, the nickel varies from 21·5 to 170 parts [45/p. 68].

The only copper, free from nickel, produced in Ontario in 1918, came from the Hudson Copper Co. at Havilah. Owing to increased freight and smelter costs, and to the absence of a custom smelter, ordinary copper mining in Ontario was unprofitable in 1918 [81].

During 1919 there were produced in Ontario 2,842 short tons of blister copper, and 9,431 tons of copper in matte. The latter compares with 22,951 tons for the year 1918. The corresponding tonnages of nickel copper ore treated were respectively 754,567 and 1,559,892. There was a considerable reduction of output after the signing of the Armistice.

Recent copper outputs of Ontario are as follow :

	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Short tons	6,471	7,474	19,681	22,499	21,434	23,557	12,273	16,030	6,382

[82]

Quebec

Copper mining in Quebec is of minor importance. A few mines are being worked in Sherbrooke Co., but operations have been carried on there for over 40 years. The ore is chalcopyrite and is associated with schistose porphyries and andesites of pre-Cambrian age. J. A. Bancroft recently reported on the district for the Quebec government, with the object of finding out if many of the abandoned properties could be reopened if a custom smelter and chemical works were provided [83].

At Capelton, the Albert Copper Co., organized to take over the interests of the Nichols Copper Co. of Quebec, operates the Albert mine of 640 acres. The mine has been developed from 6 shafts, from 500 to 2,000 ft. deep. There are 5 miles of workings. The ore-bodies are lenses of chalcopyrite and pyrite, assaying up to 5% copper and 38% sulphur. The company owns a 150-ton concentrator, a smelter and an acid plant. The chemical works cost about $1,000,000 and are among the most complete in the world for making sulphuric, nitric and hydrochloric acids, and glauber salts. The cinder, resulting from burning the cupriferous pyrite for making sulphuric acid, is smelted in the small blast furnace, which produces from 1 to 2 tons of matte per day. This is shipped to the Laurel Hill works, New Jersey, for refining. The mine produces about 175 short tons copper per year [9/p. 1605].

The Eustis mine of the Eustis Mining Co., Ltd., also in Sherbrooke Co., has been worked since 1870. The mine contains 4 lenses of cupriferous pyrite interbedded in talcose schist, which is crossed by diorite dykes. It has been worked to a

depth of 3,450 ft. on a 45° incline. The ore is dressed in a 300-ton concentrating mill and the selected ore and concentrate are shipped to various acid works from which the cupriferous cinder is sent to the Norfolk smelter. About 30,000 tons of cupriferous pyrite were produced per year. Operations were stopped in April 1919, owing to small demand for pyrites [9/p. 1606] [84/1919. p. 35].

The Suffield, King, Silver Star and Marrington mines are in Ascot township, 7 miles from Sherbrooke, contain 3 lenses of ore from 3 to 20 ft. in width and have been developed to 400 ft. in depth. The ore is estimated to contain 4 to 5% copper; a trace to 10% zinc; 5 to 25 oz. silver and 1½ dwt. gold per ton. The properties are considered promising, but developments were stopped in 1914, and no shipments of ore have been made.

The Weedon Mining Co., Ltd., operates a 375-acre property in Wolfe Co., which in 6 recent years has produced 260,000 tons of cupriferous pyrite ore. This has been mined for sulphur as well as for copper. The ore is stated to assay 3·3% copper, 40% sulphur, and to carry small amounts of lead, zinc and precious metals. In 1916 there were produced 2,800 short tons of copper. In 1919 the mine output was reduced to about 90 tons of ore daily, or about one-quarter that of the previous year [10/p. 1657], whilst in 1920 it was about 45 tons daily.

Copper contents in annual shipments of pyritic ore from Quebec for acid-making are as follow:

	1916.	1917.	1918.	1919.	1920.	1921
Short tons .	2,852	2,508	2,935	2,876	563	133

[84]

Yukon Territory

Copper mining in the Yukon is carried on mainly in the Whitehorse district, where the deposits are contact ones between Carboniferous limestones and intrusive granite. In 1917 the district produced 1,091 short tons of copper, which was shipped from Skagway by U.S. Alaskan steamers [55/1917].

The Grafter mine of 50 acres area (elevation 3,822 ft.) is 7 miles from the terminus of the White Pass and Yukon Railway. It lies in an area of alternating bands of limestone

and diorite, with cross dykes of aplite. The ore consists of magnetite, bornite and chalcopyrite in a garnet-augite gangue, and is estimated to contain 8% copper and 3 dwt. gold per ton. Between 1915, when the mine was unwatered after a shut-down, and the end of 1917, 50,000 tons of 6% copper ore were shipped to the Tacoma smelter [9/p. 1608].

The Yukon Copper Co. holds the 420 acres of the Pueblo group and the 300 acres of the Carlisle group, in the valley of Porter Creek, 4 to 7 miles west of Whitehorse. The Pueblo ore-body is of irregular shape, about 400 ft. long by 200 ft. wide, and is enclosed in crystalline limestone near a granite contact, the limestone replaced having been cut before by granite dykes. The ore is a cupriferous hæmatite, in which the copper sulphides have been altered principally to malachite, but also to chrysocolla and cuprite. The mine was shut down in 1918. A shipment of 700 tons of roughly-sorted ore, sent to the Crofton smelter, assayed 5% copper and up to 2 oz. silver per ton.

The Carlisle mine, 2 miles away, is being developed, and has a 15 ft. vein with a 4 ft. paystreak containing bornite and chalcopyrite.

Recent outputs of copper in the Yukon Territory were as follow:

	1915.	1916.	1917.	1918.	1919.	1920.
Short tons .	207	1,404	1,230	310	83	139

No shipment of ores was reported in 1921.

Newfoundland

According to the Reports of the Geological Survey, Newfoundland, the Lauzon or serpentine copper-bearing rocks of the island have a development of 5,079 sq. miles. The Lauzon forms a portion of the Quebec group, which corresponds, in part, to the Llandeilo series of the Ordovician system of Wales. According to William Logan and Sterry Hunt, the Quebec group is the great metalliferous formation of North America.

The principal copper deposits occur in Notre Dame Bay, on the east coast. The Union mine, situated at Tilt Cove, has hitherto proved by far the most productive one. The

mine was first worked in 1864 or 1865, and was described by Alexander Murray in 1867 [85]. The country is chloritic slate, very ferruginous, with seams of serpentine, and with huge intercalations of a calcareous diorite. The ore-body is underlain on the S.E. by a bed of a soft steatitic character, and contains masses of serpentine and soapstone with magnetite disseminated through it in grains and crystals. The usual underlying rock is dolomite, below which are slates, quartzite, diorite, etc. Overlying the ore-body is a grey diorite or trap, probably intrusive, with epidote, in strings and patches, and bitter spar (a brown variety of dolomite), which is succeeded by serpentine. The ore-bearing parts usually have been found to end abruptly against a wall of hard diorite on one side or the other. Here and there the rocks are in a shattered condition, and quartz veins are present. The exposed surfaces of the ore-bearing parts of the formation are characterized by a great abundance of compact pyrite, as well as magnetite, sometimes in huge masses, jasper, iron ore and specular ore (variety of hæmatite). The principal copper ore is chalcopyrite, which is frequently associated with blende; secondary malachite occurs here and there. After 42 years of continuous operation, the mine began to show signs of exhaustion in 1905 [86/1905, p. 7].

In the vicinity of the Tilt Cove mine, the Great Northern Copper Co. (of New York) holds 526 acres of freehold and is said to have a vein 160 ft. wide, uncovered for half a mile, and opened up to a depth of 200 ft. The ore is chalcopyrite, and the average copper content is said to be over 2%. The ore reserves have been estimated at 9 000 000, tons, with 500,000 tons blocked out. The company has a 1,500-ton coarse-crushing plant, and a 150-ton concentrator, and was expected to start operations in 1919 [10/p. 1659].

Bett's Cove mine, south of Tilt Cove, was opened in 1874. In 10 years it produced 130,682 tons of ore and matte, and 2,450 tons of pyrite. It was closed down in 1885.

From the Little Bay mine, upwards of 100,000 tons of copper ore have been shipped from 1880 to 1892. The Hydro-Electric Smelting Co. of Newfoundland was developing this old copper property.

At Sunday Cove Island, at the mouth of Hall's Bay, the deposits appear to consist of small lenses up to 3 ft. or so in width. The ore is said to average from 9 to 12% copper. There has been some development work, and the ore in sight has been estimated at from 1,500 to 3,000 tons.

There is a copper property near Hall's Bay, upon which some development work has been done. It is said that the ore from a shaft 60 ft. in depth and a cross cut, 75 ft. in length, has averaged between 2 and 3% copper, and that in places, the ore for a width of 5 to 7 ft., will average 6 to 8 % copper. From surface indications the length of the deposit is believed to be 1,500 ft. (E.–W.).

At Rabbit's Arm Bay, east of Hall's Bay, slate bands occur, impregnated with quartz and copper ore, similar to those at Tilt Cove, Bett's Cove and Little Bay. They strike E.–W. and dip S., and are crossed by newer fissure veins, which are also copper-bearing. The deposits occurring on the north side of Crescent Lake, 15 miles south of Little Bay mine, were first discovered in 1877, and have been worked to a vertical depth of 140 ft. For some time a mill was in operation. The strata of the region are strongly folded and consist of chloritic, steatitic and jaspery slates, intersected by numerous dioritic and dolomitic bands, and with frequent veins of quartz and bitter spar (dolomite). The main band dipped S.34°, was 15 ft. in thickness and consisted from roof to floor of: Copper ore and quartz, 4 ft.; mineralized rock, 3½ ft.; copper ore and quartz, 5 ft.; high-grade ore on the foot-wall, 2½ ft. The whole averaged 3% copper, whilst the foot-wall pay-streak averaged 12%.

It is estimated that in the few years the mine was worked about 2,000 tons of ore were raised, viz. 1,000 tons of 12% ore, and 1,000 tons of lower-grade ore.

At Seal Bay, farther east, there is said to be a lode 340 ft. in length and 60 ft. in width. Samples of dump ore and concentrate gave 3 and 4 % copper respectively. At some depth blocks of ore containing 3·8 to 6% copper have been obtained. The ore appears to be a cupriferous pyrite, and is low-grade as regards copper-content. There is a copper mine at New Bay, which was under development in 1907.

The Terra Nova mine, Baie Verte (across the peninsula from Tilt's Cove) was worked by the Newfoundland Exploration Syndicate in 1903, and 11,000 tons of cupriferous pyrite were shipped. In 1904 the output was 19,312 tons. The pyrite was used in the manufacture of sulphuric acid, the copper being saved as a by-product. The deposit at and near the surface consisted of an enormous mass of pyrite, with an occasional admixture of chalcopyrite. Native copper in small quantities was occasionally found in the serpentine [85/p. 105]. The mine, which is owned by the Cape Copper Co., Ltd., is idle at present. At Goose Cove, Hare Bay (N.E. coast), ore occurs which, on analysis gave 6·8% copper, $2·48 gold, and 57 cents silver per ton [86/1906, p. 7]. Some 700 tons of ore had been raised up to the end of 1908 [87].

At St. Julien, south of Hare Bay (N.E. coast), 280 tons of ore were raised in 1904—80 tons of which consisted of high-grade chalcopyrite [86/1904, p. 14].

In the immediate neighbourhood of St. John's City, in the south, bornite ore occurs, containing 58% copper.

Oderin Island, a little north of Jude's Island, lies on the west side of Placentia Bay in the south. Native copper was discovered here by R. McGrath, about 1900. The copper occurs in lumps ranging from a few ounces up to 55 lb. in weight, in amygdaloidal trap rock, and in quartz and calcite veins cutting the latter [88]. The formation belongs to the Huronian series of the Algonkian (pre-Cambrian). There appear to be numerous veins, having various directions, from a few inches up to 11 ft. in thickness. Samples from the veins yielded up to 6% copper. Tetrahedrite was found in one place.

Very rich ores of chalcocite, tetrahedite, and bornite are found in the Huronian series in the southern part of the 'sland [87].

At York Harbour, Birchy Cove, Bay of Islands (W. coast), there is a deposit of copper ore from which 15,000 tons of ore were raised in 1904. The deposit occurs as lenses, in serpentine, of compact, close-grained cupriferous pyritic ore with 2 to 4·5% copper, and 38 to 41% sulphur. A shaft, 360 ft. in depth, has been sunk at an angle of 72°. The mine has been closed down for years [10/p. 1660].

In 1907 copper was discovered on one side of the Red Indian Lake (centre) by the Newfoundland Development Co. (Harmsworth) [87]. The Terra Nova Properties own rights of over 2,500 sq. miles surrounding this lake, and hold a 99-year lease. The principal property is Buchan's River mine, about 5 miles west of the lake on the north shore. Ore occurs in sericitic schists formed of volcanic grits, the vein having a strike of N.51°E., and dipping about 30°. The ore-body is from 5 to 10 ft. thick, 350 ft. long, and has been proved to a vertical depth of 370 ft. The ore is a complex sulphide carrying 2·38% copper, 8·14% lead, 20·38% zinc, 6·70 oz. silver and $2·72 gold per ton.

From 1888 to 1906, inclusive, the production of copper ore in Newfoundland amounted to 1,031,546 tons, or an average of 54,294 tons per annum. About 90% of this output was from the Tilt Cove mine.

AUSTRALASIA

Australia

Production of copper in Australia until about 1900 was mainly from rich oxidized ores, whilst at the present time almost all ores mined are pyritic.

It is likely that the majority of the small high-grade deposits, hitherto the main source of supply, have been discovered. There are probably many places on the continent, especially in North Queensland, where there are large low-grade deposits, which could be profitably worked on modern large-scale lines. Scientific prospecting is being stimulated in all the States at present.

Due to the after-effects of the war, the copper industry in Australia, in common with that in other countries, is very much depressed (1921) and the majority of mines are closed down.

Outputs of copper in ores mined in recent years are as follow:

	Long tons.		Long tons.
1911	45,505	1917	39,531
1912	45,044	1918	38,968
1913	40,046	1919	19,258
1914	39,794	1920	26,695
1915	39,281	1921	18,634[1]
1916	39,564		

[1] Smelter production.

For the period 1913–20, the average annual percentage productions of copper in Australia by States have been as follow: Queensland, 50·3; South Australia, 17·4; Tasmania, 16·6; New South Wales, 13·6; Western Australia, 2·1.

New South Wales

Copper mining in New South Wales dates from the year 1844 or 1845. The principal producers are in the districts of Cobar, Mt. Hope and Nymagee, which are in a vast arid plain bounded by the Darling, Bogan and Lachlan rivers. This copper-bearing area has an extent of about 6,700 sq. miles.

The ores consist of cupriferous pyrrhotite mainly with about 16% silica and 4% copper; there are also a little chalcopyrite, bornite, pyrite, magnetite and some bismuthinite. The deposits are mostly interbedded veins in slates and sandstones of Silurian age. At Mt. Hope, 100 miles from Cobar, the ores are in diorite and andesite.

The mines, so far opened up, have been only worked intermittently. At present none is in operation and the smelter of the English and Australian Copper Co. at Newcastle has been closed down. At Port Kembla, however, the plant of the Electrolytic Refining and Smelting Co. of Australia, Ltd., has recently been enlarged. This company refines the copper produced from Mt. Morgan, Hampden-Cloncurry and Mt. Lyell mines, and also purchases ore and matte from other mines.

At Mt. Hope the dumps are treated by the Pechey leaching process, which is very similar to that used at Rio Tinto, Spain, the great difference being the method of keeping up the necessary supply of sulphuric acid to effect the solution of the copper. In the Pechey process dilute sulphuric acid is poured over the oxidized ores, and it is said that dumps containing an average of 3·2% copper are reduced to 1% after six years' intermittent treatment [89].

This does not compare favourably with the high extraction by the Rio Tinto process (upwards of 95%, after 10 years' treatment), but the latter does not appear to be suitable for oxidized ores.

The State produced an average of 4,770 tons of copper during the years 1913–20, more than one-half coming from the Great Cobar mine, at Cobar; the balance was mainly from the C.S.A. mines and the Gladstone mine, also at Cobar, the Mouramba mines, the Mt. Royal mine at Tottenham, the Abercrombie Copper mines at Burraga and the Mt. Hope mine. From 1876 to 1913, inclusive, the Great Cobar mine produced 95,489 long tons of copper. There have been no separate returns since 1913. The mine was closed in 1919.

The total amount of copper (in ingots, matte and ore) produced in the State to the end of 1920 was 261,121 tons of value £15,256,078 [90]. In 1920 and 1921 the production (excluding ore) amounted to 1,290 and 499 tons, respectively.

A company, Metal Manufacturers, Ltd., has been erecting works, near the Port Kembla electrolytic refinery, with the object of starting a copper manufacturing industry in Australia.

Northern Territory

The Woggaman geological province in Northern Territory, of 600 sq. miles area, consists mainly of metamorphic rocks of igneous origin, and in it copper lodes, with gossan outcrops, occur along shear zones in association with graphitized and actinolite schist.

There is a fissure lode at the Philip Greet's Copper mine, near Mt. Shoobridge, from which, between 1901 and 1911, about 350 tons of ore, with more than 25–30% copper, were shipped. It is considered by G. J. Gray [91] that there should be large quantities of payable sulphide ore below the present shallow workings.

The Dead Finish mine, abandoned in 1909, contains two intersecting lodes; the older lode contains rich carbonate ore; the newer lode, containing graphitic rock with copper carbonate, can be traced for 400 yd., is 9 ft. wide and is said to contain 5% copper. Gray considers that this lode at water-level will contain rich secondary ores.

Numerous, but shallow, abandoned copper prospects occur in the Margaret district, and others in which copper is in association with gold and lead in the Brock's Creek district.

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Queensland. Mt. Elliott is the largest producer of the district. Recent satisfactory developments of the famous Mt. Oxide mine, of Mt. Elliott, Ltd., have taken place. At the 208-ft. level, ores of width from 12 to 25 ft. carry from 8 to 22% copper. Taking an average width of 18 ft. on the development work done, some 300,000 tons of 10% copper ore are available. At the deepest level (300 ft.) massive chalcocite in places is abundant, and everything points to a very deep-seated copper mine in high- and medium-grade ore [93]. From the Hampden South Consols 100 tons of 8% ore was produced per day for some time in 1917, and about 80 tons per day was produced in 1918. The mine has reserves of 400,000 tons of 4% ore. The Great Australia mine, of the same company, at Cloncurry, has a large deposit of copper-bearing limestone, up to 100 ft. wide at the 300-ft. level, with 100,000 tons of 2½% ore blocked out, and 80,000 tons of 4% ore in a jasper lode.

The Hampden Cloncurry Copper Mines, Ltd., is another large company, owning 12 mines in the south part of the Cloncurry district and the Macgregor-Cloncurry group, acquired in 1913. The most important of these mines is the Hampden, which is 600 ft. deep, with a 250-ft. shoot of ore, varying in width from 3 to 30 ft., and averaging 9% copper. There is great impoverishment at the 600-ft. level. The Trekelans mine has 45,000 tons of 10% reserves, not including at the 400-ft. level a 4½ ft. shoot of ore averaging 16% copper. This mine had produced about 18,000 tons of copper ore up to the end of 1918, and later was producing about 2,500 tons per month. The company had in 1921 an estimated ore reserve of 135,000 tons containing 7,110 tons of copper and about 60,000 tons of lower-grade ore. It owns 2 smelting plants with one converter, and in the year 1920-21 produced 3,952 tons of blister copper, 2,301 oz. gold and 19,729 oz. silver. The company has been recently erecting a concentrating plant to treat a large quantity of 4% ore [70/1922, p. 253].

It is stated in an article by S. Harris, in the *Chemical Engineering and Mining Review*[1] that there are millions of tons of 3 to 5% copper ores in the Cloncurry district awaiting a large-scale treatment scheme. Under present conditions, these

[1] *Eng. and Min. Jour.*, Feb. 15, 1919, p. 302.

ores cannot be handled at a profit. The erection of a central metallurgical plant is recommended, capable of dealing with the different kinds of ores met with in the district, which vary from highly-basic to highly-acid, the latter predominating. Some ores can be smelted directly: others would require preliminary concentration before smelting, whilst some could be leached.

The famous Mt. Morgan mine is situated about 25 miles from Rockhampton. It was first opened up in 1886 as a gold mine on the siliceous hæmatite gossan of a huge pyritic lode. In 1903 gold-copper ore was discovered and a separate plant, consisting of furnaces and converters, was erected, and copper production commenced in 1906. In 1912 the gold treatment plant was closed down, and in 1914 additional smelting and other plant, including wet concentration, and later, a flotation plant, was put into operation.

The total yield in 1920–21 was 5,149 tons of copper and 73,463 oz. gold. The ore reserves at May 30, 1920, were estimated to be 3,437,000 tons valued at 2·59% copper and 6·11 dwt. gold per ton [70/1922, p. 375].

In the Chillagoe mineral field at Cardross are the Arbouin copper mines, first known in 1897. The Mammoth Copper Mine, Ltd., acquired the principal producing mines in 1911, proved the Chieftain mine to a depth of 310 ft., erected a blast furnace in 1912 and a concentrating plant in 1914. At the outbreak of war almost all work ceased in the district. The field is remote and the company advocates the building of a branch railway from the Chillagoe Co.'s terminus.

The geology of the district has been described by Lionel C. Ball [94].

The early production of the field is unknown. According to the annual reports of the Department of Mines, the production from 1909 to 1915 inclusive was 1,256 tons of copper from 12,687 tons of ore. The output of the mines of the Mammoth Copper Mines, Ltd., from October 1912 to March 1917 was 3,327 tons of matte and 905 tons of ore, the metal contents of which were: Copper, 1,258 tons; gold, 1,655 oz.; silver, 59,472 oz.

During the years 1911–18 the production of copper of Queensland averaged 20,358 tons per year, but recently it has

been much restricted. In 1919, 1920 and 1921 productions were 9,996, 15,897 and 2,428 tons.

South Australia

Copper ore was first mined in Australia in 1843 at the Kapunda mine, 50 miles N.E. of Adelaide. In 1849 smelting for matte was begun, and later fine copper was produced. After 29 years' working and the production of over 50,000 tons of copper the mine was closed down. In 1845 the Burra Burra mine, near by, was found. This was at one time the richest copper mine in the world. For the first 250 to 300 ft. in depth blue and green carbonates were worked: below this, to a depth of 600 ft., various copper sulphides including bornite, were found. The deposit consists of 2 parallel lodes striking N.W. and S.E. and dipping N.E. about 70°.

In 1860, within a short time, the famous Wallaroo and Moonta mines were found in the Yorke Peninsula. Both were operated by the Wallaroo and Moonta Mining and Smelting Co., Ltd. The Wallaroo contains 3 distinct veins all in mica-schists of Cambrian age, which are overlaid with a recent deposit of quartzose limestone. The veins vary in thickness up to 30 ft., and consist mainly of quartz, chalcopyrite and some pyrite, with hæmatite and molybdenite. They do not outcrop. Below the limestone, the lodes in the upper part show secondary minerals: for the first 90 ft. mainly carbonates with some native copper; for the next 200 ft. chalcocite; below 300 ft. chalcopyrite. The copper content of the ore for a long time averaged 12%. The mine is 2,900 ft. in depth.

At Moonta are 5 important veins, varying in thickness up to 20 ft., consisting of quartz with chalcopyrite, pyrite, and bornite, in highly-inclined masses of porphyry, covered with a layer of limestone. The dressed ore from this mine averaged for a long time 18% copper. The mine has a depth of 2,520 ft.

The Wallaroo and Moonta Co. has a smelter at Port Wallaroo.

The mining area of Yudnamutana, near the north end of Flinders Range, known since about 1865, has been described by L. Keith Ward and R. Lockhart Jack [95]. The lodes lie along the outer fringe of an area of metamorphosed sedimentary

rocks of Cambrian age. Only oxide ores have been worked. The primary ore contains pyrite and chalcopyrite. The Lyndhurst has been the principal mine. There has been little production in the district in recent years.

In 1920 development was resumed in the new Burra Copper mine, formerly known as the Utica, 6 miles S.E. of the old Burra Burra mine. The lode strikes N. 40° W. and dips S.W. 63°. The width is 4 ft. At water-level (103 ft.) malachite, chalcopyrite, chalcocite, and bornite are irregularly distributed in quartz. The primary minerals appear to be chalcopyrite and pyrite [96].

At Pernatty Lagoon, west of Lake Torrens, are impregnations of horizontally-bedded sandstones. The ores are atacamite, covellite, bornite, and chalcocite. Copper has also been found at Callington, 36 miles from Adelaide.

In 1881 there were 19 copper mines in operation in South Australia. The output of copper from the State from 1911 to 1920, inclusive, has averaged 6,250 tons per annum, most of this having been produced by the Wallaroo and Moonta Co., which, in 1918, yielded 9,290 tons of refined copper, including 1,454 tons electrolytic and 2,266 tons of blister copper from ores of the Mt. Cuthbert Co. The production of 1919 was small, owing to the low price of copper, whilst those of 1920 and 1921 were 4,339 and 1,532 tons.

Tasmania

Copper is found in several places in Tasmania, but the chief deposits are situated in the west coast range, Mt. Lyell being the best known. This was first worked in 1886 as a gold mine in a big gossan, which in 1890 was found to be that of a huge pyritic lode. The deposit is generally considered to be a metamorphic-contact, the ore, consisting of chalcopyrite and pyrite with gold and silver as accessories, being in a broad band lying between chlorite-schists and massive conglomerate. The pyritic mass is highly inclined and has locally undergone much secondary enrichment [45/p. 347].

The mine with others of similar character in the neighbourhood is owned by the Mt. Lyell Mining and Railway Co., Ltd. The company has 11 smelting furnaces, a converter

plant, and a flotation plant. For the year 1921 there were produced 5,786 tons of fine copper, 178,380 oz. silver, and 4,744 oz. gold. The company possesses water rights at Lake Margaret, 5 miles away, and runs all its plant hydro-electrically. Its ore reserves at September 30, 1920, of Mt. Lyell and South Mt. Lyell were estimated at 1,802,000 tons of value 0·5% copper, 1·5 oz. silver and 0·8 dwt. gold per ton; and of North Mt. Lyell, at 1,013,000 tons of value 6% copper, 1·33 oz. silver and 0·1 dwt. gold per ton [70/1921 and 1922].

Numerous but very low-grade copper ore deposits occur in the Mt. Pelion district, near Lake McRae. Narrow felsitic dykes of basic character and quartz-filled fissures all striking N.N.W. diagonally cross intercalated bands of quartz and mica-schists, striking E.-W. One of the dykes, largely of chlorite, dips east and on that side the greatest mineralization has occurred. The ore minerals are pyrite, arsenopyrite, specularite and pyrrhotite, with subordinate chalcopyrite. Actinolite ore-bodies, heavily pyritized and striking E.-W. replace certain strata. They contain small amounts of chalcopyrite, blende and galena. None of the ore-bodies has been proved to be of economic value [97].

The Mt. Lyell is at present the only copper mine operating in Tasmania. For the period 1911–18 the State's output of copper averaged 6,453 long tons: those of 1919, 1920, and 1921 were 5,027, 4,791, and 6,181 tons respectively.

Victoria

Victoria has produced 18,730 tons of copper, value £215,797. There has been no production in recent years.

Copper occurs associated with hornblendic dykes, either as sulphide in solid veins, or disseminated. Copper has been mined at Thomson River, where the sulphides below the oxidized zone were associated with platinum and palladium. Reference to this association has already appeared in the Imperial Institute monograph on *The Platinum Metals*. Native copper has recently been found at Carrajung, South Gippsland, in decomposed volcanic rocks—basalt and possibly tuff—near Tertiary grits and sands. The deposit is being prospected [98].

Western Australia

Up to the end of 1920 Western Australia had produced 227,786 long tons of ore, containing 24,263 tons of copper, valued at £1,600,385. There has been a gradual decrease in production since 1910. Financial assistance is now being rendered leaseholders by the Government with a view to stimulating production.

Many small deposits of copper have been found and sometimes worked in about sixteen different parts of the State, often in inaccessible places where water and fuel are scarce. The chief fields or districts, in order of total production of copper to 1920, are: West Pilbara, Phillips River, Mt. Margaret, Northampton, and Peak Hill Goldfield. There has been no production from the Northampton field for many years, and none from Mt. Margaret since 1906.

West Pilbara.—Rich copper and lead deposits were first discovered in 1872. Up to the end of 1920, 10,739 tons of copper had been obtained from 81,181 tons of ore. The Whim Well mine is responsible for about 90% of the above production, and in 1919 was practically the only producer in the West Pilbara field, where 1,031 tons of ore were raised. The lode strikes N.-W. and dips N.E. 25° and consists of lenticular masses of ore in a copper-stained kaolinic deposit 3 to 30 ft. in thickness. The country rock is a highly laminated micaceous slate of sedimentary origin, which is traversed by dolerite dykes. The lenses are made up chiefly of malachite, azurite and tile ore (earthy cuprite) with some chalcocite and melaconite. The lode has been proved by sinking and by bore-holes to a depth of 800 ft. on the dip. The ore averages 6% copper [89].

Phillips River.—Up to the end of 1920, 8,332 tons of copper have been produced from 95,537 tons of ore. A Government smelter was erected in 1905. In 1920 only 217 tons of ore were raised. The deposits are contact ones between granite and schist, and may be either auriferous copper-bearing quartz veins or basic dykes, occurring along shear lines and shatter belts impregnated with copper.

Mount Margaret.—Up to the end of 1906, when production

ceased, 4,448 tons of copper had been produced from 47,860 tons of ore, mainly from the Anaconda mine, Eulaminna district. The ores are chiefly sulphide in a siliceous gangue, but at a depth of 300 ft. there is only pyrite.

Northampton.—This district yielded 9,532 tons of copper ore, mainly between 1853 and 1864 [99].

The output of copper in Western Australia for the period 1913-20 inclusive has averaged 769 long tons per annum.

Papua

Early in the century J. McDonald discovered copper in the Central Division of Papua, and the Astrolabe Copper Field was proclaimed, December 21, 1906. It is situated in the S.E. part of the island, close to Mt. Warirata, 6 miles S.E. of Mt. Lawes, and 4 miles N.E. of Bootless Inlet.

J. E. Carne [100] has reported on the field. The geological formations appear to consist of altered and indurated sedimentary rocks (originally sandstones, mudstones, conglomerates, and limestones) intruded by gabbro and basalt. The copper deposits invariably occur close to gabbro. The zone of enrichment is so very superficial that the future of the field must depend on low-grade pyritic ores.

The Dubuna lodes occur in a narrow belt of sedimentary rocks, included between a massive development of intrusive gabbro and a narrow dyke of basalt. The former rocks consist of highly calcareous slate, in places almost becoming limestone. The country has been subjected to great stress and strain, resulting in shearing, fracturing, dislocating, and faulting.

The Dubuna mine has been worked to a depth of 200 ft. In 1919-20, 1,750 tons of ore were mined containing 6% copper. The Laloki mine has been proved to a depth of 140 ft. In 1920 the reserves were estimated at 200,000 tons of 5% ore with 40% sulphur and 2·5 dwt. gold per ton. In 1919-20, 5,966 tons of ore were mined containing 5·2% copper. A 42-inch gauge railway is in course of construction from Bootless Inlet to these mines, and a jetty is being built at that port with berth accommodation for ships drawing up to 20 ft. It

was proposed to erect a smelting plant at the same place for the production of blister copper, and there was an agreement between the New Guinea Copper Mines, Ltd., which owns the Dubuna and Laloki mines, and the Government for an hydro-electric plant to be installed at the Rouna Falls, which are only a few miles from the mines [101].

This project was abandoned as, owing to the high sulphur content of the ore, it has been decided to send the ore to Australia so that the sulphur may be utilized in the manufacture of superphosphates. The ore before shipment will be subjected to a " flashing " or superficial roasting process for the removal of free sulphur, to reduce the chance of spontaneous combustion in transit [103].

In the southern part of Woodlark Island or Murua, off the S.E. extremity of Papua, copper exists, in apparently payable quantities, close to deep water. In 1916-17 a body of ore, over 18 ft. in thickness, averaging 10% copper, was being mined and exported for treatment in Australia [102].

The Mt. Louis copper prospecting areas are in the Rigo district. The average percentage of copper in the ore appears to be about 4·7. No ore with less than 10% copper will pay to work in this locality at present.

From 1906-7 to 1918-19 inclusive, 7,921 tons of ore, value £111,085, were exported from Papua. This ore was high-grade, on account of transport and other difficulties. In 1919-20 there were no exports, pending the construction of the railway to the chief mines. Moreover there was a shortage of native labour during that financial year.

New Zealand

Deposits of copper minerals, mostly chalcopyrite, exist in about 50 places in New Zealand, but nowhere in sufficient quantity for economic mining. A small output of ore was formerly produced from Kawau Island, in Hauraki Gulf; from Great Barrier Island; from the Perseverance mine, Collingwood Co., and from D'Urville Island.

There has never been any noteworthy production of copper ore in New Zealand.

Fiji

About 1907 copper ore was discovered in two localities in Viti Levu Island, Fiji Group. In the province of Namosi, 12 miles inland, it occurs in what is described as basaltic andesite. Prospecting licences have been held on one property for some years. Samples which came from the above were examined at the Imperial Institute early in 1916. One rich sample consisting of a mixture of chalcopyrite, bornite and rock matrix, yielded: Copper, 39·39%; lead, 1·27%; gold, 2 dwt. and silver, 10 oz. per ton. Another sample, described as silicified lode matter containing chalcopyrite and pyrite, gave: Copper, 7·05%; gold, 6 dwt.; and silver, 28½ oz. per ton. Two other samples, described as altered igneous rock and silicified lode matter containing pyrite, blende, galena and a little chalcopyrite, assayed: Copper, 0·96 and 1·89% only.

Another deposit of similar ore occurs in the middle of the island and is said to assay as high as 20% copper, with some gold and silver [104].

CHAPTER III

SOURCES OF SUPPLY OF COPPER ORES (*Continued*)

(*b*) FOREIGN COUNTRIES

EUROPE

AUSTRIA

THE mining of copper has been carried on for a long period in Austria, but in recent years production has been small, that of the Empire of Austria-Hungary for the years 1910–1914 averaging 3,262 metric tons.

At Mittelberg, in the Salzburg Alps, a bedded lode in Silurian clay-slate has been mined for a long time. The filling of the lode is a sericite rock (*Lagerschiefer*) in which are irregularly distributed masses of pyrite and chalcopyrite, sometimes in masses and otherwise disseminated [47/p. 439].

By-product copper is obtained from veinlets at Schwaz, Tyrol, which contain lead, antimony, silver and copper ores. At Kitzbühel, Tyrol, occur bed-like quartz lodes containing chalcopyrite and pyrite, with, sometimes, tetrahedrite and millerite (NiS) [105]. In the Kupferplatte mine are 9 bedded veins which have been mined for 2,000 ft. in length and 530 ft. in depth. Chalcopyrite with pyrite occur as impregnations, or in lenticular masses, in slate. Similar veins, but containing lamellæ of quartz parallel to the stratification, and locally known as *Falkenschiefer* occur in the Kelchalpe mine. The chief deposit has been worked for a length of 3,530 ft. and a depth of 1,650 ft. Chalcopyrite is the principal ore, but niccolite (NiAs), chloanthite ($NiAs_2$), blende and galena are subordinate.

BULGARIA

Many deposits of rich copper ore are to be found in Bulgaria, but there was no appreciable output until 1914.

The Plakalnitza mine at Zgorigrad near Vratza is worked to a depth of 220 ft. and both copper and argentiferous-lead ores are mined. The daily average output in 1910–11 was 60 tons of 5 to 7% copper ore, which was smelted at Elisena. The mine was worked by the Germans during the war. Germans are said to be in control of another deposit in the hills of Kara Tepe, west of the Bay of Burgas. There are other deposits known to be farther south towards Sozopo and Kainarja.

A deposit at Belogradchik in the Western Balkans and one at Vratza, containing zinc also, are being slightly worked. Other copper deposits are to be found near Sofia and near Slivno.

The output of copper ore in Bulgaria for the 9 years to 1910 was 63,017 tons, that of 1909 being 19,000 tons [52/No. 22, p. 99] [57/No. 1,155, pp. 108, 115].

Czechoslovakia

Copper deposits have been recently discovered in Czechoslovakia in the neighbourhood of Beneschau, near Konopischt, and are being developed with local capital. In addition to copper the ore is said to contain gold to the amount of 22 dwt. per ton [106].

Finland

Copper mining was carried on at Pitkäranta in Finland from 1820 to 1903, with an average annual production of 350 tons of copper. The ore occurs in a dyke-like mass of contact-metamorphic limestone, enclosed in granite, and consists of chalcopyrite disseminated in the limestone. Ore minerals of zinc, tin, lead, silver, and iron are also present. The property was bought by the Ladoga Lake Mining and Smelting Co., which soon ceased operations for want of capital. The ore-body is 15 ft. thick and has been traced for 1½ miles: there are said to be 12,000,000 tons of ore in sight [107] [108].

The Finnish-American Mining Co. owns 4 groups of mines, in an area of 90 sq. miles. The principal mine, the Orijarvi, which has been worked since 1757, is 50 miles from Helsingfors and contains large ore-bodies, lying in siliceous limestone, near an intrusive quartz-diorite contact. The ore contains chalcopyrite, blende and galena (auriferous and argentiferous)

associated with pyrrhotite. Total copper production has not exceeded 4,500 tons. The average copper content is 0·6%. Selenium is associated with the gold.

Adjoining this mine is the Illijarvi, of 3 sq. miles area, which contains a siliceous chalcopyrite vein.

The other mines of the company are the Hokka and Kykka, near the Illijarvi; the Brödthrop, of 20 sq. miles in area, 4 miles from the Orijarvi, and the Kerkela, in Finnish Lapland, which carries gold ore. After an expenditure of £50,000, which demonstrated the worth of the properties, the company, on account of local prejudices, as well as legal and other annoyances, suspended operations [9/p. 1809].

Recent diamond drilling has disclosed further considerable supplies of ore and arrangements were made in 1920 to reopen these old mines and to treat by modern methods not only copper ore, but also the lead and zinc ores, hitherto neglected. The values of the contents per ton of ore so far mined in Finnish marks (1 mark = 9½ pence, normal) have been: Copper, 100; zinc, 130; lead, 30; silver, 30.

During recent years large deposits of chalcopyrite and sulphur ore have been discovered in the so-called "Kalevian" rock strata, which run from Lake Ladoga towards the Ulea marshes, and thence towards the north. The most important of these are the copper deposits at Outokumpu, which in size and metal content deserve to be described as the Finnish Falun. The ore-body was discovered in 1909 as the result of tracing a boulder containing copper to its source 30 miles away to the N.W., where after some diamond drilling had been made a blind lode was found 3 to 30 ft. thick, which was traced for 2 miles. The ore-shoot follows a fissured zone in quartzite dipping 50° S. The ore contains copper, 4 to 6%; zinc, 1·15%; sulphur, 28%; with gold and silver in small amounts. At a depth of 600 ft. the ore-body has still a maximum thickness of 28 ft. The ore in sight is about 8,000,000 tons: probable ore, 50 to 100% more. The ore has been treated by the Hybinette (electrical) process at Imatra. The yearly production capacity is 6,000 tons of copper. It is said that a continuation of this field has been discovered and has been proved to be valuable [108]. The mines were leased to Germans in 1921 [55/1921, p. 177].

France

In Alsace-Lorraine are copper ore deposits at Mollau and at Wesserling, which have been worked, but low productions have not justified their further exploitation. At Sainte-Marie-aux-Mines are very old mines, which were exploited by the princes of Lorraine till the seventeenth century, but were abandoned after the Swedish invasion. The industry here never properly recovered, and ceased in 1826 [52/No. 30, p. 97].

Production of ore in France is negligible, the largest output in recent years being only 1,377 metric tons in 1917, so France must buy copper abroad. French companies, however, control some production in Serbia, Lower California and South America, and some of the French colonies, especially in Africa, possess promising deposits of copper ore [109].

The following are recent imports of copper materials (metric tons):

	Ore.	Ingot and Mfrs.	Sulphate.	Oxide.
1913 .	9,653	138,510	21,575	96
1914 .	10,717	86,140	24,071	62
1915 .	2,758	120,127	33,868	10
1916 .	1,501	175,000	20,943	12
1917 .	4,030	240,138	43,214	63
1918 .	427	166,781	42,426	6
1919 .	1,000	56,042	17,266	35
1920 .	2,845	73,756	16,141	35

[55/1920]

Germany

Almost all the copper production of Germany comes from the Mansfeld stratified deposit, which extends over an area 120 miles long and from 60 to 90 miles wide. The deposit, known as the Lower Zechstein formation, consists of a bed of bituminous shale, 18 to 23 in. thick, between sandstones of Permian age. The whole of the shale is cupriferous, but the profitable portion, *kupferschiefer*, which is also the most bituminous, is only 3 to 6 in. thick.

The mining of the deposit began in 1199: the industry was nearly extinguished in the Thirty Years War, but was revived in 1671, and in 1852 the present company, which works

the deposits, was formed by the consolidation of the various interests. Mining is now confined to the Mansfeld area, but at one time there were extensive operations at Riechelsdorf, at Bieber and near Saalfield.

The principal ore mined from a width of 8 to 12 in., including the kupferschiefer, contains chalcopyrite, bornite and chalcocite, disseminated through the shale. The average copper content of the ore mined, after sorting, is about 3%, the silver content, 0·016%. It is considered that the copper sulphides have been the result of the reduction of copper sulphate by the abundant organic remains, chiefly those of fishes, which occur in the schist.

The hand-sorted ore is first roasted in heaps, mainly to destroy the bituminous matter, and is then smelted in blast furnaces, a 40% matte being produced. This matte is roasted in calcining kilns, and the roasted product, mixed with 5 to 10% raw matte, is smelted in reverberatories to white metal containing 74 to 75% copper. Full details of the company's mining and metallurgical operations are to be found in a pamphlet by Leon Demaret, chief engineer of the *Corps des Mines*, Brussels [110].

In 1912 the treatment of 873,305 metric tons of sorted ore produced 20,173 tons of copper. The estimated yield in 1916 was 26,340 tons copper: that of 1919, 10,605 tons.

During the war the operations of the company were curtailed by shortage of coal; they are now carried on at full capacity, the company making use of much of the 3,000 H.P. of water power, recently developed in the Upper Harz region [9/p. 1802] [45/p. 325] [47/p. 399].

Copper is mined in several other places in Germany, including Rhenish Prussia, the Harz, Saxony and Lower Silesia, but the total production from them is small.

The lodes at Altenberg, near Seitendorf, Saxony, to the north of the Bergmannstrost lode carry so much copper that before the discovery of their valuable gold content they were regarded as copper lodes.

At Kupferberg there are both contact beds and contact lodes in an area of hornblende-schists next to granite, the former being nearer the granite. The ores are principally chalcopyrite and bornite. Mining on these deposits has ceased [13/1, p. 403].

The large deposit of pyrite at Rammelsberg, near Goslar, Harz Mountains, has been worked for copper since the tenth century. It is described in the Imperial Institute monograph on *Lead Ores*.

Recent productions of copper from native ore in Germany from official sources were as follow:

Year.	Metric tons.	Year.	Metric tons.
1911	22,000	1917	27,000
1912	27,400	1918	25,000[1]
1913	26,600	1919	26,000[1]
1914	25,100	1920	27,000[1]
1915	26,300	1921	19,000[1]
1916	31,000		

[1] Estimated.

Germany's pre-war importations of copper of late years were large, and increased very rapidly. In 1912 she imported from the United States 98,852 metric tons; in 1913, 127,463 tons; in 1914, 141,156 tons. The importation in 1913 amounted to one quarter of the entire world's production. During the period 1904–13 the imports were 2,000,000 tons.

Germany's pre-war consumption amounted, ordinarily, to 8 lb. per head per annum. A large proportion is usually exported in many manufactured forms [55/1914, p. 193].

During the war, in spite of strenuous efforts, Germany was only able to produce about 40,000 tons of copper per year. A Serbian mine provided another 10,000 tons. Prior to 1914 about 260,000 tons per annum were consumed in various industries, about 60,000 tons being re-exported.

Electrolytic iron was used during the war to meet the dearth of copper for such purposes as the manufacture of shell bands, and two factories were erected each with a capacity of 200 tons per month, but electrolytic iron is too expensive for common use. When copper became unobtainable, brass was treated by oxidizing the zinc and casting the 98% copper thus obtained into anodes for electrolytic refining. Later on, the supply of brass gave out and bronze was used. As the tin in this could not be removed by oxidation, the anodes were cast from bronze direct [111/No. 5,553].

As mentioned before, experts estimated that after the war

about one-third of the previous requirements of copper would be replaced by aluminium, and to a much less degree by zinc [111/No. 5,145], but this was falsified, contrary to expectations, and the consumption is steadily increasing.

GREECE

Copper is obtained in small quantity on the island of Skyro, Greece, and is known, but not worked, on the islands of Eubœa, Samos, Mytilene, Paros, Imbros, Thasos, and Andros, and in the Othrys and Taygetus ranges on the mainland [52/No. 11, p. 64] [57/No. 1221, p. 151].

In Grecian Macedonia copper ore has been mined in Limogardi [52/No. 18, p. 99].

HUNGARY

The principal copper deposits of Hungary are at Schmöllnitz, where masses of pyrite and chalcopyrite, some of large dimensions, occur in a zone of clay-slate interstratified with mica-schists. At Herrengrund, near Neusohl, small bed-like lenticular masses of tetrahedrite, associated with chalcopyrite and quartz, occur in gneiss. At Schemnitz, copper is obtained as a by-product from silver, lead, and other ores [47/p. 450].

ITALY

Deposits of copper in Italy are principally confined to the provinces of Tuscany and Liguria. Those of the Massa Marittima occur as fillings of Eocene fault fissures of considerable width, the ores carrying about 3% copper in chalcopyrite: associated minerals are galena, blende, calamine, and argentiferous fahlore. The deposits of Monte Cattini in the Tuscan Apennines are serpentized portions of gabbro and diorite intrusions [45/p. 166].

The Libiola Copper Mining Co., Ltd., formerly operated the Libiola mine—an old Roman mine, reopened in 1867—in the Carrara district, not far from Genoa. The mine has veins in dolerite and serpentine carrying chalcopyrite with pyrite. The production in 1918 was 1,001 tons of copper ore and 12,926 tons of pyrite, and in 1919 was 436 tons of copper ore and 2,964

tons of pyrite. The mine was closed down in 1919 [70/1921, p. 325].

Other mines in the Genoa district are the Monte Loreto and La Cascine. In the Aosta Valley of the Turin district are the old mines San Marcello, Champ de Praz and Ollomont [47/p. 471].

In the Trentino are several copper deposits reported to be rich. Mines were being worked, at least till recently, at Canale S. Bovo, not far from Fiero di Primiero on the eastern frontier, and at Val d'Avisio, near Mezzavalle, 12 miles farther north [52/No. 33, p. 26].

Productions of copper in Italy in recent years, in metric tons, are as follow:

Year.	Metal.	Year.	Metal.
1914	1,839	1918	1,114
1915	1,840	1919	1,243
1916	1,807	1920	450[1]
1917	1,248	1921	1,900[1]

[1] Estimated.

[112]

The following is a summary of the copper trade of Italy for some pre-war years, in metric tons:

Year.	Production.	Imports.	Gross supply.	Exports.	Net supply.	Consumption.
1911	1,666	28,510	30,176	743	29,433	29,400
1912	2,319	33,031	35,331	1,717	34,200	33,600
1913	2,400	30,280	32,680	1,465	31,200	39,100

[9/p. 244]

NORWAY

The copper mining industry of Norway, formerly very important, has been established for centuries. The metal occurs in chalcopyrite and cupriferous pyrite. Ores of the former have an average copper content of about 5%, whilst cupriferous pyrite ores, which are mined and exported mainly for their sulphur content, contain on an average about 1½% copper and 44% sulphur. Within recent years there has been a revival of copper mining due to development of water-power for the

generation of electricity, but at the present time a large number of mines are inoperative.

A small amount of copper has been recovered as a by-product by a nickel-refining company at Kristiansand from nickel ore. Until lately all copper ore has been smelted with imported coke, but now electric-smelting is being introduced.

There are 3 distinct ore-fields in Norway in which copper is found, which are situated respectively in the south, in the central northern part mainly in the province of Trondhjem, and in the north.

The mines in the southern part, which have outputs of cupriferous pyrite ranging up to 27,000 tons per year, are in a continuation of the large ore-belt of Central Sweden, and include those at Röstvanger on Tinoset; at Bossmö and Rödjfeld near Mo in Ranen; at Stordö Island off Hardangerfjord; at Viksnes on Karmö Island and at Undal, north of the Naze. The last are rich, but are unprofitable to work owing to the absence of transport facilities [57/No. 1214].

In Central Norway are the principal copper-bearing deposits of the country, which are at Röros and in the Dovrefjeld in Trondhjem. These are similar to true veins, but differ in being always conformable to the country rock, which consists of Lower Cambrian mica- and chlorite-schists and clay-slates. The deposits are very irregular in size, and contain pyrite, chalcopyrite and pyrrhotite. The usual copper content is a little below 2% [47/p. 523].

The Aamdals Kobberverk owns a 3,000 acre property at Foldal, which has been mined for over three centuries. The ore has, as chief minerals, chalcopyrite and bornite, the latter being primary and found below the chalcopyrite, and contains about 2% copper. The company completed a new concentrating plant in 1915, and was building an electric furnace in 1919. It produces about 900 tons of concentrate per annum containing about 225 tons of copper.

The Foldal Copper and Sulphur Co. holds 3,000 acres at Foldal on the Glommen River, on which are the 6 old mines Juliana Marie, Knutshovd, Foldal, Grey, Moltke and Grimsdal, which have been worked for the last 150 years. The ore is in a vein 12 ft. wide and consists practically of massive

cupriferous pyrite. It contains 2% copper and 46% sulphur. The company owns extensive mine plant, a hydro-electric power plant and a 22-mile aerial tram, one of the longest in the world, which takes the dressed ore to a quay at Trondhjem, whence it is shipped to England. It mines about 60,000 tons of pyritic ore per annum containing about 1·8% copper and 44% sulphur [10/p. 1811].

The Orkla Grube-Aktiebolag owns a mine at Meldalen. The deposits are lenses in gabbro, and the ore is a cupriferous iron pyrite containing 2% copper and about 43% sulphur. In 1915 the production was 180,000 tons of cupriferous pyrite ore; in 1916, 100,000 tons.

The Grong Mining Co., mainly French, was formed in 1913 to work rich deposits of cupriferous pyrite near the Swedish frontier at Skorovas near Tunnsjön; at Gjersvik on Limingen, and at Joma, near Huddingsvand. The annual output, mainly of value for its sulphur content, amounts to about 200,000 tons a year [57/No. 1214].

In Northern Norway are mines at Sulitelma; at Ballagen on Ofotenfjord, and at Folsteid on Vaagö in the Lofoden Islands.

The Sulitelma mines, about 15 miles east of Fineidet, a port on the Saltenfjord, are within the Arctic Circle. They were discovered in 1885. The ore, in lenses, consists of a cupreous pyrite and pyrrhotite, disseminated through mica-schist. Some of the pyrite is massive. The ore is sorted into 4 grades:

	Copper. %	Sulphur. %
(1) Sulphur ore . .	3	44
(2) Copper ore . .	6	32
(3) Concentrating ore .	1·8	22
(4) Waste . . .	0·25	3

The first is shipped away for acid making; the second is smelted on the mine by the Knudsen discontinuous pyrite process; and the third is dressed by the Elmore Vacuum process, after a wet concentration plant separation. With the Elmore process a concentrate is obtained containing from 6 to 8½% copper, with an extraction of over 80%. The total

production to May, 1919, was 1,917,354 tons of cupreous pyrite ore and 368,836 tons of smelting ore [10/p. 1813] [113].

The Ilen Smelting Works, in the province of Trondhjem, a few years ago made a pioneer trial of smelting copper ore in an electric furnace of 1,000 h.p., estimated to be able to produce 2,000 tons of copper a year. The first 25 tons of copper produced and exported in 1913 came from ore of the Bitovaria mine, at Kaafjord [29].

Some recent productions in Norway in metric tons are as follow :

Year.	Ore.	Ingot copper.	Year.	Ore.	Ingot copper.
1912 .	60,018	2,130	1917 .	39,298	1,810
1913 .	70,349	2,741	1918 .	50,034	2,856
1914 .	57,951	2,800	1919 .	—	1,800
1915 .	50,097	2,828	1920 .	—	1,400
1916 .	28,070	1,614	1921 .	—	1,400 [1]

[1] Estimated.

[55/1920] [114]

Productions in Norway of cupriferous pyrite in 1917 and 1918 were 326,000 and 325,000 metric tons respectively. Of these amounts 214,000 and 234,000 tons were exported as here shown :

To	1917.	1918.
Sweden	106,000	109,000
Denmark	20,000	3,000
England	77,000	112,000
Holland	11,000	10,000

Nearly all Norway's copper production is exported to Germany, Sweden and England, for conversion into manufactured copper and brass goods, and is reimported. Her consumption of copper, mainly as copper wire, in the past has been slightly higher than her production, but since the war the consumption has increased 3½ times, that of 1913 being

2,000 tons, and that of 1919, 7,000 tons, the United States supplying the deficiency above production [115].

Recent exports of copper from Norway are as follow:

	1914.	1915.	1916.	1917.	1918.	1919.
Metric tons . . .	2,558	2,691	1,430	1,900	1,254	394

[114]

Poland

Near Kielce in Poland is the Medzianka Gora mine, which has been worked since 1400. The ore-body is a tabular contact deposit between Devonian bituminous slates and granite; it varies from 1 to 3 ft. in thickness and contains from 1 to 3% copper. The ore contains malachite, azurite and chalcopyrite in limestone. The Germans were operating the mine during the war [107].

Copper ore exists in other parts of Russian Poland, and copper mining was formerly of some import, but most of the mines were closed down some time ago [52/No. 44, p. 85].

Portugal

Nearly all the copper deposits of Portugal are to be found in the southermost part of the country, the most important centres being San Domingos, Aljustrel and Grándola. These are on the extension into Portugal of the great copper-bearing belt of Huelva, Spain (*see* p. 115). The Minas de San Domingos, an old mine, operated by the Mason & Barry Co., is the principal producer. It is near the Spanish border, in an arid region, about 30 miles inland, and is connected by a railway 7 miles long with Pomarão, on the Rio Guadiana, which is navigable to the ocean. The ore contains 0·91% copper, and 48·28% sulphur; the ore-bodies are lenses of cupriferous pyrite in Devonian schists. The mineral zone is 2,000 ft. long and 200 ft. wide. The mine is opened to a depth of 700 ft. The copper content of the ore decreases with depth, but the value mainly depends on its high sulphur content. The copper from about one-fifth of the ore mined is extracted by leaching, the remaining ore being shipped as pyrite. The tonnages of ore mined in 1918, 1919 and 1920 were 80,079; 69,522 and 93,812.

About one-half is shipped away. The reserves in 1918 were 7,500,000 tons [55/1920, p. 174] [70/1921, p. 346].

In the Aljustrel district, next in importance but at present inoperative, is the Minas de San João do Deserto, owned by a Belgian company. In 1914, 164,465 tons of ore were mined. From this were produced by the smelting of concentrate 1,229 tons of 77% matte. The matte was shipped together with 39,539 tons of pyrite ore. Chalcopyrite ore is also mined at Barranços and at Serra da Caviera, silver and gold being by-products at each; at Tinoca and at Azeiterios, in the north of Beira Baixa; at the Vale do Bicho, in the Arouca district; and at Zambijeiro, near Evora. At Palhal, in the province of Aveiro, are important copper deposits containing nickel. There is little recent information available [116].

The following are estimated copper outputs for recent years:

	1914.	1915.	1916.	1917.	1918.	1919.
Metric tons . . .	4,570	4,290	4,308	4,300	4,000	2,300

Rumania

Deposits of copper ore exist in Rumania in the departments of Mehedinți in Wallachia, Suceava in Bukowina, and Tulcea in the Dobrogea. In Mehedinți at Baia are undeveloped chalcopyrite veins in a large mineralized zone. The Rumanians extensively worked chalcopyrite deposits in the Tulcea district just before their entry into the war. The Germans continued the exploitation of these deposits and sent away much copper ore to Germany [52/No. 23, p. 105].

In Transylvania copper is a by-product in the production of gold and silver, but there has been a gradual decline in the industry in the last 50 years. There are still workings in the Hunyad district at Almasel and Veczel, and in the district of Csík.

Copper minerals occur in the mountain region in the S.W. of Banat and there are argentiferous copper mines at Oravicza-bánya and Uj-Moldova [52/No. 6, pp. 51 and 66].

Russia (in Europe and Asia)

Copper mining has been carried on for a long period in Russia, which before the war held the sixth place in the world as

a copper-mining country, producing about 4% of the world's total, about two-thirds of the output coming from the Ural district.

Up to 1850 Russia was an exporter of copper; then for 30 years the industry declined. After 1880 there was an increased production; but Russia then was a large importer as well, the production of copper being only about three-quarters of the consumption.

In 1906 the industry was stimulated by an import duty on all copper products, equivalent to £32 per ton, and growth of production was rapid, as will be shown by the following table of annual outputs in long tons, from the various districts, including Finland and Poland, now independent states (*see* pp. 90 and 100).

District.	1901.	1906.	1910.
Urals	3,501	4,677	10,791
Caucasus	3,980	3,829	7,593
Siberia, Kirghiz Steppes and Altai	508	665	3,217
Finland and Poland . .	295	38	911
Totals	8,353	9,209	22,512

[117/p. 215]

Recent annual total productions, imports and consumptions of copper, in long tons, are as follow:

Year.	Production.	Importation.	Consumption.
1913 . . .	33,795	6,300	40,095
1914 . . .	31,414	13,000	44,414
1915 . . .	25,599	42,500	68,099
1916 . . .	21,487	23,890	45,377
1917 . . .	16,000	—	—

[36/1919] [118]

Imported copper has been almost entirely electrolytic, being used mainly for telegraph, telephone and tramway work. Electrolytic copper has been produced so far, in Russia, only by the Kyshtim Corporation and by the Rosenkranz Co. of

Moscow, the latter refining blister copper, which they purchase. It is probable that Russia could easily produce all the copper she needs.

The Russian Copper industry up to recently was controlled by a syndicate, the "Mjed," formed in 1907, which regulated the production and sale of copper till 1914, when it lost control of its board owing to a regrouping. Under the Bolshevists the syndicate was "socialized." In 1913 it owned 38% of the total output, sold a further 30½% belonging to associated companies, whilst 27% was produced by allied works. The sole selling agents of the syndicate were Wogan & Co. of Petrograd, which were placed under State supervision at the beginning of the war. This firm was largely responsible for the increased copper production in Russia, the introduction of the electrolytic refining process, and the imposition of the import duty on all copper products [117/p. 217].

Till recently half the copper produced was due to Anglo-Russian companies. British capital has been largely interested in Russian copper and other mining ventures for the last 100 years, and British technical skill has been very helpful in the development of copper production.

Under Soviet rule there was a general decline in copper production from 1917 to 1920, when the output of ore was only 3,600 tons, so the industry, like some others in Russia, has become insignificant.

The Urals

The mining district of the Ural Mts. is one of the richest regions of the world. It is fairly well developed by railroads, and there are good resources in water-power and forests of timber. Mining is conducted on very big estates of feudal origin, each of which usually contains both copper and iron mines. In the year 1913 the district produced over one-half the total output of Russian copper.

Towards the north the department of Perm, on the eastern slope of the Ural Mts., is the Bogoslovsky Estate, of the Société Minière de Bogoslovsk, which controls 2,000 sq. miles of freehold, as well as 1,350 sq. miles of leased crown forest lands. Mining dates from 1745, but has been spasmodic until recently.

Since 1912 the estate has been connected by a 120-mile railway with the Perm Railway, upon which, within a belt 4 miles long, there are the four principal producing mines, Vassibyevsky, Bogoslovsky, Frolovsky and Nikitinsky. The first contains lenses of pyritic ore, irregular and small in size, but of high grade, 13% ore being shipped practically without sorting. The second is nearly exhausted, having yielded so far over 1,000,000 tons of 5½% ore. In the last two mines the ore is in the form of either tabular lenses or vertical columns. The deposits are contact metamorphic ones, and the ores consist chiefly of chalcopyrite, with some pyrite and pyrrhotite, but chalcocite persists in one mine to some depth. Small amounts of gold and silver are present. The estate is equipped with a modern 700-ton smelter, with converters and electrolytic refinery. In 1914, 65,000 tons were mined, 4,200 tons of copper being produced at a cost of 4¼*d.* per pound. The estate recently was the third largest producer in Russia [107].

The Mjednorudiansk (Demidoff) Co. owns the estate granted to Prince Demidoff by Peter the Great. The estate has an area of 2,150 sq. miles, and before 1906 was the largest producer in Russia, having yielded already 3,000,000 tons of 2% ore. Till recently one mine only, near Nizhni Tagil, was worked. The ore-bodies are contact-metamorphic deposits, between Devonian limestone and diorite. The ore consists of cupriferous pyrite, which is covered with a deep zone of oxide material, celebrated for its malachite crystals. The mine is approaching exhaustion. Its production recently was about 1,400 tons of copper per year.

The Verkh-Issetsky Co., on the estate of Count Stenboch-Fermor, at Kalata, 145 miles north of Kyshtim, Eastern Urals, is working two groups of mines, the Pyshminsky-Klyutchevsky, near Ekaterinburg, and the Kalatinsky mines at Nevyansk. The former contains a contact-metamorphic deposit, which, in 1912 yielded 3,482 tons of copper from 10% ore. The latter contains a pyritic replacement deposit of 2·3% ore, which is almost solid pyrite, containing 43% iron and 50% sulphur, with only 2% silica. The ore has been used till recently as a source of sulphur for acid making, but now the mine is equipped with a smelting plant, consisting of 2

blast furnaces and 2 converters, turbo-blowers, a refinery and a 3,000-kw. power plant. In 1915 the tonnage of ore treated was 169,760 with a fuel consumption of 1·66% of the charge, or 2·49% of the ore, practically pyritic smelting. The slags contain 0·33% copper. The company was recently producing per annum about 1,700 tons of copper [9/p. 1815] [36/1919] [119].

The Sissert Co., Ltd., owns the Sissert Estates of 340,000 acres, situated about 30 miles south of Ekaterinburg in the Urals, and connected with Perm by railway. The property contains many old copper, iron and gold mines. The copper deposits are rich and extensive, the principal mines being the Polefskoy and Gumeshevsky, worked since 1727, the Sysselsky, opened in 1906, and the Degtiarsky. The two first, 500 ft. deep, produced, up to 1870, 31 500 tons of copper from oxidized ore only. The ore-body is a contact deposit, lying between limestone and syenite. The oxidized ores, which carry malachite, cuprite, and native copper, are found in a clay belt about 2 miles long and 1,000 ft. wide. The sulphide ores carry chalcopyrite in lenses of garnet-magnetite rock. Cupreous selenium is found in the mines.

The Gumeshevsky ore dumps, residuals after hand-sorting and still containing 500 000 tons, were being leached in an acid plant at the rate of 80 000 tons a year. Old slag dumps of the Polefskoy, containing 640,000 tons, are to be reworked. These are said to contain 1% copper, of which 75% can be recovered by smelting.

The Sysselsky, developed to 245 ft. in depth, had, in June 1916, 70,000 tons of reserves of 4·2% ore; has a plant of productive capacity of 1,500 tons of copper per year, and was recently considered able to produce copper at 5*d.* per lb.

The old Polefskoy smelter has recently been remodelled and its capacity has been increased.

Drilling on the Degtiarsky mine has disclosed 3,530,000 tons of 2·77% ore. The ore-body is about 10,000 ft. long, of which 5,800 ft. has been proved. It is expected that 5,000,000 tons will be developed ultimately.

Recent productions of copper from the Sissert Co.'s mines were :

	1912.	1913.	1914.	1916
Long tons	1,464	1,293	956	226

[10/p. 1878]

Operations have been only intermittent latterly.

The Kyshtim Corporation, Ltd., now merged with the Russo-Asiatic Consolidated, Ltd., controls an estate of 2,198 sq. miles in area, which includes 189,000 acres of mineral land, containing important iron and copper mines in the Government of Perm, Southern Urals. The company is the largest copper producer in Russia, its principal operating mines being the Konyukoff, the Smirnoff, the Tissoff and the Amerikansky. The ore-bodies, described by A. W. Stickney [120], are large pyritic lenses, which are replacement deposits similar to those at Huelva.

The company owns a smelter at Karabash, consisting of three blast furnaces, one reverberatory for treating fines and flue dust, and one gas-fired regenerative-type reverberatory for fine ore ; an electrolytic refinery at Kyshtim, and plants for making acid, copper sulphate and dynamite. The smelter has a capacity of 10,000 tons per year, but has not yet been worked to full capacity. In 1914, 7,600 tons of refined copper were produced at a cost of £38 10s. per ton ; in 1916, 6,600 tons. The refinery also treats the blister copper of other companies.

In January 1918 the Bolshevist government " nationalized " the mines, but nothing serious happened : the district falling under anti-Bolshevist control later, the company resumed operations in December 1918.

The company's copper ore reserves in April 1917 were estimated at 2,835,000 tons containing 2·75% copper [9/p. 1810] [36/1919] [70/1919, p. 284].

The Tanalyk Corporation, Ltd., now merged with the Russo-Asiatic Consolidated, Ltd., owns mining claims of total area 44 sq. miles on the Boorzian Estates in the country of Orsk, Orenburg Government, in the Southern Urals, as well as felling rights on 300,000 acres of forest, and prospecting rights over a further area. The principal copper mines, which are being developed at present, are the Mambet, the Tanalyk, the

Graffsky and the Ulali. The ore-bodies consist of siliceous veins of cupriferous pyrite in schist country. The company owns a smelting plant of capacity between 7,000 and 8,000 tons of ore per month. It ships its blister copper to the Kyshtim refinery. The ore of the Tuba gold mine, which contains copper, is treated by amalgamation, the tailing being smelted. During the year 1916 there were produced 687 tons of fine copper, 22,000 oz. gold and 137,000 oz. silver: during 1917 (9 months), 700 tons of blister-copper, 22,000 oz. gold and 145,000 oz. silver [10/p. 1818].

At June 1917 the total reserves were estimated at 570,000 tons of 2·6% sulphide ore, containing 0·08 oz. gold and 1·4 oz. silver per ton, and 157,000 tons of 0·38% oxidized ore containing 1·35 oz. gold and 6·7 oz. silver per ton. Operations during 1917–18 were interfered with by the Bolshevists, but were resumed on a restricted scale in November 1918.

The above-mentioned copper properties are on the east slope of the Urals, but on the west slope, and on the plains for a distance of 300 miles, there are a large number of low-grade deposits of no commercial importance, which are impregnations of Permian Red Sandstone [70/1919, p. 520] [107].

The Kargalinsky mines, owned and worked by W. A. Pashkoff, are near Orenburg and produced prior to the war about 800 tons of copper per year. The deposits differ from those of the Northern Urals in that they occur in sedimentary rocks. Copper sulphides were found in 1640, and ore was extracted in the region of the River Meleus. The Red Sandstone beds, in which the ore occurs, are mostly horizontal, the ore-bearing layers varying from 2 in. to 2 ft. in thickness. The copper content also is very varied, especially near the surface, where the ore consists of red and black oxides of copper. The ore from the Kargalinsky mines is treated at the Verkhotour works, the yield being about 2·7% copper [45/p. 312] [117/p. 216].

According to T. H. Preston [121], the following table gives in long tons the outputs of copper for the years 1913 and 1914 of the Ural district:

Works.	1913.	1914.
Pyshminsky	1,372	1,741
Kalatinsky	(building)	1,063
Polevsky	1,310	975
Voesky	1,399	1,249
Kyshtim	7,835	7,746
Bogoslovsky	4,042	3,709
Totals	15,958	16,483

The Polevsky, Kyshtim and Bogoslovsky works are British-owned.

Unusually rich copper deposits have been discovered in both the Andréevsky and Mandareff placers in the Orenburg Government. It was intended to erect a copper smelting works to aid the exploitation of the latter.

Arctic Russia

Copper ore has been found in Arctic Russia in many places in the Kola Peninsula (Archangel). It was also mined centuries ago on the River Tsilma, a tributary of the Pechora [57/No. 1207, p. 307].

Nova Zembla

The extension of the Urals to the north occurs in the islands of Nova Zembla in the Arctic Ocean.

The Nova Zembla Mining Co. of Odessa was mining a copper deposit of the Bogoslovsky type (Urals), at Propashche Bay, on the west side of the South Island. The ore has yielded up to 40% copper. After irregular working it was decided to work the deposit all the year round with 100 men, and to establish a port [107] [117/p. 218].

Caucasus

The territories of the Caucasus include Georgia and Azerbaijan, in Transcaucasia, south of the Caucasus Mts.; Russian Armenia; and North Caucasus. They are very rich in mineral wealth, and especially in copper ores. The copper-mining industry of Transcaucasia has been fully described by D. Ghambashidze [122] and the information given has been utilized below.

Next to petroleum and manganese ores, copper ores are the

most important minerals. They are found in numerous places and were well known to the ancients, who, however, only working on the surface, left the lodes untouched at depth. The ores are found generally in fissure veins and consist mainly of chalcopyrite and pyrite, with subordinate amounts of bornite, tetrahedrite and native copper, often associated with blende and galena. The lodes are found in andesite and dolerite in the form of impregnations of crushed brecciated zones [45/p. 169].

The mines are mainly in the mountains, and have been hitherto mostly left untouched on account of their inaccessibility and through lack of fuel, which has to be imported. It is probable, however, that in the future the great amount of water-power in the country will be largely converted into electric power for mining and smelting operations.

Up to the outbreak of war mines were being worked in the governments of Batum, Tiflis, Erivan and Elizabetopol. Ten years ago the Caucasus produced one-third of the total Russian output. During the war the output was reduced to one-third of that before, as the countries were in close proximity to the fighting [36/1919].

The chief copper-producing companies in the Caucasus are the Caucasian Copper Industries, Siemens Successors, La Société Industrielle et Métallurgique du Caucase, the Mezilik Azariantz Co., the Kunduroff Co. and the Grielsk Co. [117/p. 216].

The Caucasus Copper Co., Ltd. (Caucasian Copper Industries), a British-American organization, owns 6 mines, including the Dzansul, Chiakathevi and Erga in the Murgal Gorge district of Artvin, near Dzansul, 45 miles from Batum, known as the Dzansul Copper and Silver Lead Mines. The first and principal mine is 500 years old, having been worked by Italians in the sixteenth century. It was in the hands of the Turks from October 1914 to March 1915. The ore-body consists of a great lens, 1,000 ft. long, 164 ft. wide, and 328 ft. deep. The ore is chalcopyrite with some bornite, mixed with pyrite, in a quartzite gangue, and averages 3% copper [107]. The mine has been hitherto worked by open-cut methods, the overburden having been removed by hydraulicking. A steam shovel is to be used later on. The company has a 1,000-ton-a-day wet concentration plant and a Minerals Separation plant of

400 tons per day capacity. In 1913 there were produced 3,721 tons of copper at a cost of 6½*d.* per pound. In 1912 the ore reserves were estimated at 3,600,000 tons of 3·1% ore [9/p. 1809] [70/1919, p. 101].

The Kedabek Copper Works and the Mis-Dagh mine were bought by Siemens Bros., in 1864. They are on the Mis-Dagh (Mt.), at an altitude of 6,000 ft., 26 miles from Dalliar, near Elizabetopol. The ore-bodies are lenses up to 820 ft. long and 160 ft. thick in altered quartz-porphyry, which has been cut by diorite dykes. The ore consists of chalcopyrite, pyrite, pyrrhotite and blende in a barytes gangue. In 1914 there were produced 794 tons of copper from 14,401 tons of ore. The mine is connected by a pipe line with Baku, through which oil is pumped for roasting, smelting and refining operations.

The reserves of smelting ore are practically exhausted, but low-grade surface ore is being leached.

The Kvarzhana mine, purchased by Siemens Bros. in 1903, is 37 miles from Batum in the Tchorohk district. The ore-body is a single lens, containing chalcopyrite and pyrite, formed by replacement at a slate-quartzite contact. There are 500,000 tons of reserves of 4½% ore, with small gold and silver contents. The successors of the Company are erecting a smelter to produce 1,700 tons of copper annually. The property is not being worked at present.

The French company, La Société Industrielle et Métallurgique du Caucase, formed in 1888, owns 3 mines, Alaverdi, Aktala and Shambru, in the Lialvar Mts. on the railway from Kars to Tiflis, and the Synik mine in the Zanguesur district, near the Persian border. The first, the principal mine, was worked by Greeks 160 years ago. The ore-bodies of chalcopyrite and quartz are in the form of lenses in quartz-andesite. One lens is 600 ft. long, 120 ft. deep and 36 ft. in thickness. There are 3 years' reserves of 3½% ore. About 4,000 tons of copper were produced per year before the war at a cost of 5½*d.* per lb. The Synik mine contains small veins of ore in andesite or diorite [52/No. 54, p. 63].

The Khoteli mines, owned by Deboer and Gukosoff, are in the Artvin district, near Batum. New treatment plant is being erected.

The Ugurchaisky mine, owned by the Greek firm of Kundoroff Bros., is in the Zanguesur district, not far from the Persian border. It is near the Synik mine. The ore-bodies are veins from 3 to 6 ft. thick in dolerite or andesite, and the ore contains up to 15% copper. The mine is equipped with a small smelting plant. In 1913 the production of copper was 800 tons.

The Sirimaden Reduction Works are situated at Alexandropol, in the Erivan Government.

Old mines, formerly of great productivity, have been reopened in the Okchi Valley, Zanguesur district, Elizabetopol. The Katar mine in the same district is now worked by electricity. In the Pambak Mts. are the Delijan, Sirimaden, Sagali, Mishkan and Seifalu mines: the last has ore with 20 to 30% copper.

It is said that there are rich copper deposits in the provinces of Terek and Kutais, in Northern Caucasus, and that a concession covering an area of 5 sq. miles has been granted. The deposits are at a high altitude, but work could be carried on all the year. At the surface the average copper content is 3½%, but at a depth of 5 to 6 ft. the content is up to 25%. The total estimated metallic copper in the concession is 322,000 tons and it was calculated that copper could be delivered in Moscow at 6*d.* per pound. The district has good communications, is in heavy forest country and is well supplied with water-power [117/p. 218].

Some pre-war statistics of the copper industry in Transcaucasia are as follow:

Production of Copper in the Caucasus

	1911.	1912.	1913.	1914.
No. of Companies in operation:				
Having their own smelters	15	15	16	14
Without smelters	17	14	21	14
Total production, long tons	8,346	9,657	10,136	8,259
Productions of chief producers:				
Société Industrielle et Métallurgique	3,990	4,315	3,725	4,071
Caucasus Copper Co.	2,208	3,060	3,322	2,892
Siemens Bros.	1,551	1,435	1,272	794

Siberia

The principal producing district in Siberia is the Altai region. About three-quarters of the entire Siberian production until recently came from the Yuspenssky mine of the Spassky Copper Mine, Ltd., which was the second largest producer in Russia.

Altai District.—The Altai Mines, Ltd., a Russian company, owns two concessions, the Zmeinogorsk and the Zyrianovsk, in the Altai district of Western Siberia, and directly east of the Irtish River, which is navigable. The two properties are separated by the Ridder concession of the Russo-Asiatic Corporation. The former, of 12,292 sq. miles in extent, includes a large ore-body, 3,000 ft. long and 20 ft. wide, which contains, on an average, 4% copper, with much zinc, as well as lead, gold and silver. Diamond drilling to 500 ft. on the Byelousovsk copper mine, has disclosed 6% ore at that depth. This is an old mine. From 1½ to 2 million tons of 3½% copper ore with 9% zinc have been opened up. The deposit is a bedded replacement one, 20 ft. thick, on the contact between limestone and clay-slate, which has been cut by porphyry, the slate having been altered to hornstone. Owing to the complexity of the ore its electrolytic treatment is being considered. There is good water-power to be utilized near the mines.

The Zyrianovsk property, which will be developed after the organization of a Russian company has been completed, has a series of lenses of complex ore. So far 500,000 tons of ore have been developed, containing 23% zinc, 11% lead 2·6% copper, 19 oz. silver and 0·35 oz. gold per ton [9/p. 1813], [36/1919] [70/1919, p. 367] [107] [123].

Although the ores of the Altai region are mainly of zinc and lead, the district promises to be an important source of copper in future. The Irtysh Corporation, Ltd., which owns the Ridder concession, has recently been developing by drilling an important "porphyry" deposit of copper, adjacent to the Ekibastus coal field, to the west of Pavlodar: the deposit is said to be of large dimensions.

The Far East

In Eastern Siberia copper ore is found in the Minusinsk district of Yeniseisk Province; near Verkhne-Udinsk and in the Onon and Argun basins in the province of Transbaikal; in Maritime Province, where there are deposits near Vladivostock, from which a small production has been made, and also near Konstantinovska and on the Suifun; near the mouth of the Kolima; at the confluence of the Big and Lena rivers; in the peninsula of Kamchatka and around Djigit Bay, where rich ore occurs in pockets and the deposits have been shown to be of economic value [57/No. 1207, p. 273] [117/p. 218].

There are 5 copper foundries at Blagoveshchensk in the District of Amur.

C. W. Purington [124] describes Siberia as the world's greatest storehouse of copper, as well as of gold, although it produced practically no copper prior to the closing down of the industries by the revolution; that is, excepting the production of the Spassky mine. He considers the first successful copper mining on any considerable scale will be in the "porphyry" deposits, which can be mined by open-cut methods with the steam-shovel. There are enormous tracts of territory in the mineral-bearing mountain system of the Alatau, Altai and Saran ranges, which remain to be explored. The belt is mineral-bearing throughout, with volcanic rock associations, and it is known that base metals have been mined in it by primitive peoples for a long period [125].

Kirghiz Steppes

The S.E. part of the Kirghiz Steppes, between the head waters of the Irtish River and the Syr Daria, contains about 20 copper deposits. The principal settlement, Spassky, in the Akmolinsk district, is 500 miles S.E. from Petropavlovsk on the Trans-Siberian Railway. The Russians first mined here in 1847, but there are workings of unknown age. Spassky Copper Mine, Ltd., formed in 1904, owns smelting works and copper mines at Spassky, the Yuspenssky copper mine, the

Karagandy and Saran coal mines and other mines, of a total area of 100 sq. miles, and a 26-mile railway between the smelter and the Karagandy coal mine. The smelter capacity is 400 tons of copper per month [70/1921, p. 556]. The property was "nationalized" by the Bolshevists in April 1918, but was handed back later. Operations have only been intermittent lately and on a very small scale.

In the Akmolinsk region Permo-Carboniferous rocks are common, but the oldest rocks are quartzites and phyllites (Devonian ?) associated with porphyries and serpentine. The igneous rocks are mostly volcanic and generally older than the sedimentary. The Yuspenssky deposit, crescentic in form and mostly E.-W. in direction, dips generally to the south. It lies between older massive igneous and sedimentary rocks (foot-wall) with younger highly-fissile stratified rocks (hanging-wall), which are black and carbonaceous, and highly shattered. The deposit exhibits various zones of copper content downward: Surface impoverishment, from 10 to 15 ft. in depth; oxide enrichment, 15 to 200 ft.; sulphide enrichment, 200 to 450 ft.; and normal or primary sulphide down to 700 ft. or more. The lode is richest near the hanging-wall, and decreases in value towards the foot-wall. One ore-shoot at 350 ft. depth was 300 ft. long and 45 ft. wide: another at 280 ft. depth was 180 ft. long and 50 ft. wide. Barytes is common with the richer ore. Bornite and chalcocite are the principal ores, the bornite being gradually replaced by chalcopyrite in depth. Tetrahedrite is found. Native copper and oxidized ores are found in the upper workings.

From 1906 to 1915, inclusive, the total output of copper was 29,494 tons: the average of 1913 and 1914 was nearly 5,000 tons. The grade of the ore is between 16 and 22% copper. The blister copper contains gold and silver to the value of £5 per ton. In 1909 it cost 4·4*d*. per lb. to produce, but in 1912 the cost had been reduced to 3*d*. At the end of 1919 the reserves were reported to be 420,000 tons of 7·8% ore. The richer ores have been smelted at Spassky with a Russian-type furnace, without water-jackets, and converters. A concentrating plant using the Minerals Separation Flotation process was built at Sara Su, near Yuspenssky, to treat lower-grade ores,

and a reverberatory furnace was erected at Spassky to smelt the concentrate produced. The concentrating plant was burned down in 1919. The Spassky Co. some years ago bought a quarter interest in the Moscow Electrolytic Works Co. and in 1912 the properties of the Atbasar Copperfields, Ltd.

The Atbasar group of mines covers an area of 28½ sq. miles, and lies about 250 miles east of Djousalie, the nearest station on the Orenburg-Tashkent Railway. The copper deposits are at Djes-Kazgar, 260 miles west of the Yuspenssky mine. The settlement, with concentrator and smelter is at Karsak Pai. A coal mine at Bai Kanour, 85 miles to the west, is included in the group. Some of the workings are probably four or five centuries old. Modern operations commenced in 1913 after incorporation with the Spassky Co.

The deposits are confined to the highest Permo-Carboniferous sedimentary rocks—sandstones, conglomerates, shales, thinly-bedded limestone and cherts. They are tabular in form, or "sheets," and bear a great resemblance to the zinc-lead deposits of Joplin, Missouri. They are invariably associated with faults. Some contain 30,000 to 50,000 tons of ore each. The thickness varies from 1½ to 5 ft. The original ore is chalcopyrite, bornite and pyrite; and the gangue, calcite, quartz, barytes, siderite and dolomite. The workings are only 300 ft. deep, but boreholes have been put down to 700 ft. [126].

At the end of 1915 reserves were 544,000 tons of 10% ore, including 150,000 tons of 13·1% ore ready for stoping. A concentrating and smelting plant has been designed of capacity 5,000 tons of copper per annum.

Spain

Copper mining in Spain is carried on mainly in the province of Huelva. The deposits, generally referred to as the Rio Tinto deposits, occur as masses of pyrite, with some chalcopyrite, and stretch for many miles in a general east and west direction. The pyrite is mined mainly for its sulphur content, the percentage of copper being, as a rule, low.

The pyrite zone is about 25 miles in width, and about 120 miles in length, viz. 50 miles in the province of Huelva, 30 miles in the province of Sevilla on the east, and 40 miles in Portugal

on the west. In the Rio Tinto region, Palæozoic sediments—Cambrian, Silurian and Lower Carboniferous—lie upon an ancient formation of gneiss, mica-schist, quartzite, limestone and hornblende-schist. The chief pyrite deposits occur in the Culm measures (Lower Carboniferous) near sheets, sills or dykes of rhyolite-porphyry and dolerite. The ore-bodies conform to the general strike of the country rock, and lie on the contact between porphyry and enclosing clay-slate, or are wholly within the prophyry. They are more or less lenticular in shape, with a steep dip. There has been both regional and contact metamorphism. Tectonic movements have tilted the beds and given them a general E.-W. direction, and a northerly dip. There are transverse faults, striking N.-S. and dipping E. or W., and overthrusts, the products of bending, whereby the foot-wall has been thrust over the hanging-wall. In places the ore-bodies have been considerably crushed and show brecciation. Some of the ore-bodies are of considerable length and width, but both these dimensions show a great decrease in depth. The larger deposits have been worked to a depth of 1,000 to 1,300 ft.; others have pinched out at a depth of 650 ft. from surface. A surface-zone and two depth-zones are distinguishable. At the surface, and extending to a depth of 65 to 130 ft., the deposit consists of limonite (gossan), usually without copper or sulphur.

The "cementation" or secondary enrichment zone may reach a further depth of 160 ft. or more, the ore consisting of pyrite, chalcopyrite and chalcocite. In this zone the ore occasionally contains 10 to 15% copper, the average being 4 to 5 %. The primary ore is a fine-grained compact mass of pyrite (according to De Kalb [127] it is an intimate mixture of di- and mono-sulphide of iron), with some chalcopyrite and small amounts of galena, blende, etc., with a little quartz. The copper content is as low as 1 or 1·5%. The average of the ore mined in the whole district may be put down at the highest as 2·5%. The decrease in copper with depth is a gradual one [13/1]. Besides the ordinary pyritic ore, there is siliceous ore which represents porphyry that has been sericitized, and which contains chalcocite, with 1½ to 10% copper and 10 to 15 oz. silver per ton. This ore is stacked in separate heaps for leaching

[128]. The deposits are of epigenetic origin. According to A. Moncrieff Finlayson [129] the ores of these lodes have for the most part been formed by replacement of zones of sheeted and crushed rock, and he believes them to be the end product of the magmatic differentiation to which the series of igneous rocks in this district has been due. H. F. Collins confirms this [130] and believes there has been both deep-seated and lateral "primary" enrichment as well as "secondary" enrichment.

The great Rio Tinto mine is of considerable antiquity. The history can be traced back for 30 centuries, when the Phœnicians first colonized the coast of ancient Huelva (Bœtica), but the mines were probably worked by the inhabitants (Celto-Iberians) before the arrival of the Phœnicians, for stone tools of great antiquity have been found in the old workings. Numbers of Phœnician coins have also been found.

After the Phœnicians came the Carthaginians, who were soon ousted by the Romans. Roman gold, silver and bronze coins have been found in the region, and in 1772 a copper plate with an inscription of the time of the Emperor Nerva was found on the wall of an adit, about 370 ft. from its mouth, and in 1876 a bronze tablet containing an old fragment of Roman mining law was found buried in some ancient slags near Aljustrel, Portugal, 60 miles west of Rio Tinto, on the same line of deposits. In the ancient workings themselves the remains of wooden water-wheels, with interchangeable parts, have been found. Thirteen adits, one thousand shafts (mainly circular or Roman) and millions of tons of slag testify to the extent of the ancient workings. After the withdrawal of the Roman legions from Spain, there followed centuries of inaction, or, at best, of intermittent working. Rio Tinto was neglected and forgotten. In 1556 the mine was rediscovered by Mendoza. During the next 150 years several abortive attempts were made to rework Rio Tinto. In 1725 a joint-stock company formed by Liebert Wolters, a Swede, undertook some exploratory work. On his death, two years afterwards, his rights and privileges were transferred to his nephew Samuel Tiquet, with whom Lady Mary Teresa Herbert shared the ownership. The industry was established on a firm basis under the

management of Francisco Tomás Sanz. On Tiquet's death 1758 Sanz was nominated his trustee and administrator. I the following table the output from 1739 to 1872 has bee compiled from data given by W. G. Nash [131], from whos work the above historical notes have been taken :

Years.	Administrators.	Production of copper.	Remarks.
		Long tons.	
1739 to 1758	Wolters and Tiquet (concession)	152	
1759 to 1776	Sanz (concession)	1,205	
1777 to 1799	Government	3,037	Sanz administrator 1777 t 1784.
1800 to 1829	,,	1,280	Fausto Elhuyar's Report 1823.
1830 to 1849	Marquis de Remesa (concession)	4,750	Heap roasting (*teleras*) firs used ; leaching practise since 1839. Felipe Prieto (royal patent 1845) es tablished leaching on a working basis.
1849 to 1862	Government and Concessions	1,229	
1863 to 1872	Government	9,100	
1873 to 1892	Rio Tinto Company	320,000[1]	Open-cut system adopted, 1875. Smelter erected, 1902. Improvements in leaching, railway to Huelva, pier, etc.
1893 to 1913	,, ,, ,,	431,280	

[1] Approximate only.

The Rio Tinto Co. has not published any production figures since 1913. Between 1876 and 1916 about 20 million tons of pyrites were shipped and 40 million tons were treated locally, the whole producing 730,000 long tons of copper. Drilling over untouched ore-bodies has disclosed over 130 million tons of ore, and the company has about 60 years' reserves.

The leaching or " cementation " process now employed at Rio Tinto has been described recently by Courtenay De Kalb [128/p. 191]. He states : " The completeness of extraction is remarkable. After ten years' exposure the copper is almost wholly removed ; at the same time the leaching of the copper does not lead to any extensive disintegration of the pyrite." He thinks that the reason " may be found in the fact that the copper sulphide was introduced by mineralizing agents towards

the end of the deposition of the pyrite, if not entirely subsequent to its formation."

According to the official report of the Ministrio de Fomento in August, 1917, the Rio Tinto Co. had 18,540,000 metric tons of ore stacked in the leach-piles [127/p. 126].

The Sociedad Anónima Minas de Cala, near Rio Tinto, works magnetic iron ore and cupriferous pyrite. In 1916, from 23,973 tons of crude ore it shipped 12,669 tons; of calcined ore, 7,346 tons; and of copper mineral, 1,010 tons of total value 286,536 pesetas.

The Société des Mines de Cuivre de Campanario, at Valverde del Camino, Huelva, normally leaches 40,000 tons of ore per year, and sells the residue for its sulphur.

The Sociedad Española del Castillo de las Guardas in Seville is developing 5 large ore-bodies [9/p. 1816].

The United Alkali Co., Ltd., owns several mines at Valverde del Camino, Huelva, and sends the ore produced to its own works at St. Helen's, Lancashire. In 1916 the production was 180,000 tons of cupriferous pyrite and 1,000 tons of copper precipitate [10/p. 1828].

The Esperanza Copper and Sulphur Co., Ltd., works 5 ancient mines at Zalamea La Real, Huelva. Operations commenced in 1906. From 1906 to 1918, inclusive, the production of ore amounted to 1,135,925 tons. In 1919, 33,996 tons of ore were shipped [70/1921, p. 203]. Mine liquors are treated in two leaching plants, the production amounting to about 100 tons of copper per annum.

The Huelva Copper and Sulphur Mines, Ltd., owns two mines between Rio Tinto and Tharsis. In the 3 years ended June 30, 1921, an average of 79,414 tons of ore smelted yielded 1,758 tons blister copper. The ore reserves were 113,000 tons.

The Peña Copper Mines, Ltd., owns 17 ancient mines N.E. of Rio Tinto. Some of the ore is leached, the rest being shipped. During the 3 years 1917–1920 on an average 98,000 tons of ore were mined; 102,268 were shipped and 545 of copper recovered by leaching. According to *The Times* (July 7, 1921) the ore reserves were 3,314,000 tons.

The San Miguel Copper Mines, Ltd., at Almonaster, Huelva, has produced 590,000 tons of copper ore in 10 years. From

1904 to 1915 the production of copper was 7,100 tons. The mines were reported to be closed down late in 1919 [10/p. 1827].

The Tharsis Sulphur and Copper Co., Ltd., which owns several mines at Huelva, ships large quantities of cupriferous pyrite ore, mainly for its sulphur contents. The ore is shipped to Great Britain, the residues, after the extraction of the sulphur, being treated for copper at the company's works. The output of copper in 1884 amounted to 13,544 tons and to 3,246 tons only in 1918. The big drop in output is due to the low copper content of the ore now being worked.

The Cordoba Copper Co., Ltd., operating 10 miles N.E. of Cordoba, produced 1,554 tons of copper from 61,373 tons of ore in 1917; 1,453 tons from 46,369 tons in 1918. In 1919 the yield was 284 tons of blister copper. In September of that year the company announced the sale of its mining properties for 1,000,000 pesetas [70/1921, p. 153].

According to Courtenay De Kalb [132], a series of siderite-chalcopyrite veins occur in pre-Cambrian slates of the Sierra Nevada, Granada. The highest group of mountains in the range stands on a fault-block of large dimensions. The deposits occur along a series of parallel faults in this block, the most abundant mineralization being near a basic dyke. Near La Estrella a strong lode known as Rascal crosses the Guarnón stream. On one side of the stream the vein contains large masses of siderite with disseminated chalcopyrite (primary), and the sericitized masses are blackened in many places with sooty chalcocite (secondary). The dumps appear to contain from 3 to 4% copper. The Campanario vein dips W.S.W. 50°, or at right angles to the slate, and is from 12 in. to 3 ft. wide. The gangue is quartz and siderite, with much sericite and with bunches and seams of limonite, resulting from the oxidation of pyrite and chalcopyrite. Some selected ore appeared to contain from 12 to 15% copper. The Veta Grande has a large dump, but the workings are inaccessible. On the Bacares vein, approximately 10,000 ft. above sea-level, are five open cuts in a length of 1,200 ft. A dump of 5,000 tons probably averages 2·5 % copper. L. Legrand, who reported on these deposits in 1894, says the strike of Bacares is N. 36° W.,

the dip S.W.45°, the average width 16 ft. and the average copper content 3·79%. He found barytes in places. In other veins he found stibnite. The León de Plata vein, according to him, strikes N. 38° W., is vertical, is 20 to 23 ft. in width, and has a prominent gossan and an unusual amount of chalcopyrite. Samples of veins from two other mines yielded Legrand from 3·21 to 13·85% copper.

Some of the Sierra Nevada copper veins were probably worked by the Moors, others have been explored or exploited from time to time since, but the production has been intermittent, and small. De Kalb regards the following as the most promising veins of the district: Bacares, Rascal, Veta Grande and León de Plata. He points out that the chalcopyrite could be separated by flotation, and the iron-carbonate tailing could be utilized as an iron ore.

Recent productions of copper in Spain were as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.
Metric tons.	25,706	34,699	32,880	38,526	45,104	23,419	21,000[1]

[1] Estimated.

SWEDEN

Copper mining in Sweden is a very old industry, dating in Falun from about 1200. In the seventeenth century the country was the largest producer of copper in the world, which could have been supplied with the production in 1655 of 3,453 tons.

The principal ore deposits are at Falun and Garpenberg in the Dalarne; at Tunaberg in Södermanland; at Bersbo in Östergötland and at Äreskutan in Jämtland. A copper mine was opened in 1918 at Vittensten in Vestre Värmland [57/No. 1214]. Several copper-ore deposits have been reported at Bjornange in Jämtland; analyses were said to range from 10 to 20% copper [133].

At the present time operations are only carried on at Falun and at Helsingborg, the pyritic ore mined being used only for the production of sulphuric acid, whilst the copper produced in Sweden is derived from ore imported from Norway.

Immense deposits of copper ore have been found recently by the State geologists in South Lapland in Tärna Parish;

also at Jofjäll and Klippan (cuprite). At Unna-Greisa a vein 150 ft. thick has been discovered [134].

The following table gives statistics of production and of imports for recent years:

	Production.[1]			Imports.[1]
	Ore.	Ingot.	Sulphate.	Copper and alloys of copper.
	Metric tons.	Metric tons.	Metric tons.	Metric tons.
1913 . .	5,458	4,315	428	10,265
1914 . .	8,839	4,692	651	13,557
1915 . .	10,549	4,561	—	14,901
1916 . .	13,805	3,181	1,268	12,642
1917 . .	13,579	3,201	956	3,715
1918 . .	21,498	2,956	—	4,031
1919 . .	7,279	3,558	—	14,639
1920 . .	1,136	1,289	—	18,178

[1] Swedish Commercial Board Reports.

Turkey in Europe

A promising copper mine at Rumeli Kavak, on the European side of the Bosphorus, was shut down owing to the construction of fortifications [52/No. 16, p. 101].

Yugo-Slavia

Bosnia

The copper deposits of Sinjako, at Varcar Vakuf, Central Bosnia, consist of veins of chalcopyrite and pyrite with magnetite, barytes, etc., in Triassic sedimentary rocks near intrusive masses. From 1915 to 1917, inclusive, the production amounted to 783 tons of ore. Copper ore has also been worked on a small scale in several other places in Central Bosnia. The Maskara copper-mercury deposits have not been worked in recent years [135/p. 61].

Croatia

The Breslinats iron-ore deposits, 50 miles south of Zagreb (Agram), were formerly mined for copper. At Samobor, 12 miles west of the same place, veins containing notable quantities of chalcopyrite in Triassic sedimentary rocks near intrusive

diorite have been worked on a small scale. At Nebojan, near Petrinje, deposits of copper and iron ore of some importance have been recorded [135/p. 62].

Serbia

The two most important copper districts in Serbia are Majdanpek in the department of Tchatchak, and Bor in the department of Timok, which are on the eastern spurs of the Balkan Mts., the former being about 80 miles E.S.E. of Belgrade. At Majdanpek the deposits occur in the form of irregular masses and as impregnations at the contact of andesite with limestone (Mesozoic) and crystalline schists (Palæozoic), or in altered andesite. According to W. H. Weed, chalcopyrite is the dominant ore, whilst bornite, covellite and chalcocite also occur, the gangue being quartz. The ores average 3% copper, and contain small but recoverable amounts of gold and silver. They are smelted to black copper containing 96% copper. Pyritic masses with magnetite also occur, containing from 0·3 to 1·5% copper (as chalcopyrite), and are utilized for making sulphuric acid, the copper being extracted as a by-product.

The Bor deposits are 30 miles south of Majdanpek. The formation consists principally of Cretaceous limestone and andesite. There are five parallel copper-bearing veins in andesite, volcanic tuffs and breccias, forming a belt running north and south for a length of about 10 miles, and of a width of 1 to 2 miles. The veins, according to Weed, usually occur at the contact between unaltered andesite and propylite (altered andesite). The latter rock covers large areas. The vein-filling consists of pyrite and chalcopyrite, with some covellite, bornite, chalcocite and enargite, a little galena and blende, and some gold and silver. According to G. Gordon-Smith [136] a drift was commenced in the village of Bor, about 105 ft. below some old workings, through a propylitized mass of andesite, so altered that only a quartz skeleton remained of the original rock, with frequent cavities having the shape of felspar and ferromagnesian minerals. Some 39 samples were taken at equal distances across the mass of ore, with the result that 26 gave from 8 to 25·6%, 11 from 5 to 8%, and 2,

3·2% copper. All showed gold, from traces to 6 dwt. per ton. The ore in sight amounted to 255,000 tons. The following average results of detailed sampling are given by D. Iovanovitch [137] [135/p. 59]: *Chuka-Dulkan*, the principal workings where there is estimated to be 1,600,000 cub. metres of ore. An average of 30 analyses of samples from the huge lens of pyrite, chalcopyrite and chalcocite gave: Copper, 7%; silica, 29 to 75%; iron, 11 to 23%; vein 88½ ft. wide. *Krivelj*, copper 5·5%; vein 40 ft. wide. *Crveno-Brdo*, copper, 7%; average width 75 ft. Here are three irregular ore-chimneys developed for a length of 822 ft. and to a depth of 230 ft.

Extensive ancient workings are found both at Majdanpek and at Bor. Some at the former place date from the time of the Romans. The deposits were also worked during the period of the medieval Serbian State before the Turkish invasion. From 1870 to 1903 the production of the mines at Majdanpek amounted to 4,350 tons of copper from 115,000 tons of ore (3·78%). In 1902 the mines were leased to a Belgian company, which in 1907 erected a 200-ton smelting plant, with 4 water-jacket and other furnaces. During the Great War the mines were controlled by the Austrians.

In 1903 the principal mine near Bor was worked by a French company, and 4 small blast furnaces and converters were erected. In 1912-13 the production amounted to 7,600 tons of copper, but in the latter part of 1912 the Balkan War had greatly interfered with the output. In the Great War the area was occupied by the Bulgarians, and later by Germans, who, during the war, were able to extract much copper. The damage done to the mines on evacuation is being repaired. It is probable that the output of copper will be eventually increased to 100 tons per day. The copper produced is being exported to France and America [55/1919, p. 183].

At Zlot, south of Majdanpek, auriferous chalcopyrite occurs in andesite. Near Nish argentiferous chalcocite, chalcopyrite, malachite and azurite are found impregnating red sandstones. At Rebelj are lenticular masses of pyrite and chalcopyrite in serpentine, intrusive into Mesozoic limestones. In 1903 the 3,820 metric tons of ore mined from this locality yielded 150 tons of black copper [135/p. 60]. Elsewhere in Serbia

quartz veins of auriferous chalcopyrite occur in granite. Copper ore is also found in isolated masses in limestone, and chalcopyrite, pyrite and bismuth occur in quartz veins in gabbro [136].

The copper output of Serbia for 1920 was reported to be 2,436 metric tons [55/1920, p. 174].

Serbian Macedonia

Copper ores were formerly mined on a small scale in the Osogov Mts., at Dobrovo, and at Petchovo in the Males Mts. [135/p. 62]. Dugi Hrid, Trepatsa, Gevgeli and Gradsko in the Plachkovitsa Mts. are other localities mentioned as having occurrences of copper ore [52/No. 20, p. 91].

ASIA

Arabia

Copper ore is said to exist on Masira Island off the coast of Arabia and to have been mined there; also in Yemen, on the mainland, where it has not been worked [52/No. 61, p. 84].

China

The mining of copper in China has always been strictly controlled by the government, as copper is an important medium of currency. The metal is imported as production is insufficient to supply the needs of the country [138].

According to V. K. Ting, Director of the Geological Survey of China [139], there are many deposits of copper in China, but not many are of value. The deposits occur as (1) *magmatic segregations*, (2) *contact deposits*, (3) *replacement deposits* and *fissure veins*, (4) *impregnations*, and (5) *sedimentary deposits*.

The first are seen in the Permian basalt of Yun-nan, which covers great areas. All are small and irregular. Similar deposits occur in the Tertiary porphyries of North Chih-li. The contact deposits, always associated with iron ore, are due to contact action of diorites. They are found in South Hu-peh, in the districts of Shing Kuo and Yangshing, and are of small economic importance. The government is working a contact

deposit at Pangshih in Kirin, which contains 10% ore, but is small. Important replacements, occurring as stockworks in limestone, and as fissure veins in shale, are found in the famous Tungchuanfu mine, Yun-nan, where the ore contains over 8% copper, and in the Hueili district of Sze-chuan.

Low-grade impregnations are found in the pre-Cambrian crystalline rocks of South Shan-si and N.W. Hu-peh. The government is working a similar deposit at Penghsien, near Cheng-tu (Sze-chuan), where the ore-bodies consist of large lenses in crystalline schists and limestones, and contain about 5% copper.

The sedimentary deposits in Yun-nan and in Kwei-chow are of interest: the lower Triassic sandstone overlying the Permo-Triassic coal measures, always contains some copper, principally as malachite.

According to Chas. H. Hansen [140] great mineral wealth lies within the border of the province of Kan-su, but prospecting is very difficult, as the rocks are covered by a capping of fine sandy loam (*loess*), up to 200 ft. in thickness, supposed to have been blown over from the Gobi Desert. At one place he erected a copper smelting furnace, with a capacity of 50 tons per day, there being good fluxes and coal near by. Access is difficult as the roads are of the worst possible type.

According to H. W. L. Way [141], there are extensive aboriginal workings on the Ko-Lo-Lo copper mine, 4 miles north of Maha, Sze-chuan, and there are a number of derelict stone blast furnaces in the valley below, but the mine has not been worked within the memory of man. Copper-bearing veins occur at Lo-Ko-Ti, about 12 miles N.W. of Maha; and at Hui-Lung-Chang, 30 miles N.E. of the same place, 90 smelters worked very prosperously until 15 years ago, when the Chinese were driven out by the Lolos.

The copper mines of the province of Yun-nan have been described by J. Coggin Brown [142]. In N.E. Yun-nan the Lou Pou mines in Carboniferous porphyry yield a small production, and, near the village of Ta-Me-Ti, are several copper deposits, the most interesting of which is Lao-Sin-Chang. It is a kind of stockwork in cracked and brecciated limestone, and the primary chalcopyrite has been altered to carbonate

with concretions of barytes. The ore from Lao-Sin-Chang was almost entirely chalcopyrite, and that from Pe-Si-La was mainly bornite with a little covellite. In E. Yun-nan, the deposits at the Tien-Pao mine, near Pe-Tchen, consist of three interstratified ore-bands with a sandstone floor and a shale roof. Only one seam is being worked. The ore, in the form of balls, is chalcopyrite. The Wei Tou Chan mine is on a thin vein following an irregular fissure in an eruptive rock, carrying quartz rich in bornite, chalcopyrite and pyrite. The Yung Pei Ting district, N.N.E. of Ta Li Fu, was inspected by J. Coggin Brown [142]. He believes the veins were in very irregular fissures, very varied in size and shape, crossing shales, sandstones and limestone, and entering the eruptive rocks in contact with them. The output is at present small. The San Chia Chang copper mine, S.W. of Yun-nan Fu, in the upper valley of the eastern head waters of the Red River of Tongking, was also visited by J. Coggin Brown. The ore is chalcopyrite, with small amounts of enriched sulphides, in limestone, which is much broken near its contact with slates.

Copper mining was formerly of importance in Yun-nan. The decline in the last 50 years is due to depletion of rich surface ore, to political troubles, to lack of charcoal fuel due to the destruction of forests, and to transport difficulties. There are government mines in the Tungchuanfu region, already referred to, which yield an output of about 1,000 tons per annum. One of the mines dates from 1697, and the output from five groups of mines formerly amounted to from 4,500 to 9,000 tons per annum [138]. The Mohammedan Rebellion in 1858 stopped all mining in Yun-nan. There was a revival from 1874, and the mines reverted to the government in 1907. The government also has copper mines in the Penghsien district, near Chengtu, Red Basin, and in Hufichow, 115 miles south of Maha, Szechuan; at Ch'ang Pailing, Kiangsi, and works at Yaokai, Kansu. The Ching Hua Mining Co. is working in the Nanchang district, Hu-peh, with a modern foreign equipment.

Copper also occurs in the provinces of Shan-tung, Hu-nan, Anhui, Kwei-chow and Kwang-tung.

In Manchuria copper is found, but apparently not worked,

at Tunghwasien and at Maoerhshan near the Korean border east of Moukden; also at Pensihu, at Tienpaoshan, at Chaimachi and at Shisuitze [52/No. 69, p. 54].

According to Rockhill, copper is found and slightly worked in S.E. Tibet [52/No. 70, p. 61].

The difficulties of mining for foreigners in China are described by W. F. Collins [143], E. Gilmour Brown [144], and J. A. T. Robertson [145]. If foreigners desire to engage in mining they can do so by forming joint companies with the Chinese, half of the shares being held by Chinese. In some places, such as the province of Hunan, the presence of foreigners is not desired. In some parts large portions of the mineral wealth are locked up in concessions. The important mineral province of Yun-nan is under French control.

The yearly output of copper in China is about 2,000 tons at present, one-half of this coming from Yun-nan, the balance, from Kirin, Kansu and Turkestan [138].

Recent imports of unmanufactured copper are as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Metric tons .	15,853	2,089	1,575	1,672	7,339	19,210	25,190	28,925

[146]

Dutch East Indies

Celebes

Copper ore has been found near Gorontalo, and is being worked by natives [52/No. 85, p. 23].

Dutch Borneo

Ores of copper are fairly uniformly distributed near Mandor, Montrado and Budok, West Borneo. Copper ore is found occasionally disseminated in gold and pyritic quartz veins in slate and granite, and small veins containing pyrite and chalcopyrite occur in argillaceous sandstones. In the Tampi Mts. there is a zone of weathered clay-slate 40 ft. wide, impregnated with pyrite and chalcopyrite, and traversed by several small ore-bearing veins, which, however, die out at small depths. In the same mountains native copper has been found in auriferous drifts. The Chinese and native gold-washers

have long known that native copper is sometimes associated with gold sand; indeed, copper ore is said to have been, at one time, a by-product in gold-washing. Near Salothong, copper ore is found in granite for a width of 16 ft., either in small veins or scattered through it in nests and impregnations. At greater depth the quantity of ore diminishes. Near Skanah, granite is traversed by veins of chlorite nearly 2 ft. in thickness, containing chalcopyrite and blende. In the deserted gold mines of Man Fo Pie and Ko Pie Then, veins impregnated with chalcopyrite are scattered over a clay-slate district. Some of the veins consist almost entirely of chalcopyrite [50/p. 437].

Dutch New Guinea

The presence of copper has been reported near Biri River in the north east of Dutch New Guinea [52/No. 87, p. 23].

Dutch Timor

A rich copper deposit has recently been found near Taninj, about 20 miles from Tjamplong, Dutch Timor, the ore being reported to be worth from £25 to £40 per ton at the then existing rate of exchange [147].

Java

It is believed that copper ore exists in large quantities in Java. It is found at Madiun and at various places in the Preanger Highlands but has been mined nowhere scientifically [52/No. 82, p. 65].

Sumatra

Copper ore is said to be plentiful in the Paningahan Valley, west coast of Sumatra, but has not been worked. It is found also on Nias Island off the same coast [52/No. 83, p. 47].

FRENCH INDO-CHINA

Louis de Saugy has described the copper ore occurrences at Van Say, on the Song-bo (Black R.), a tributary of the Song-kio (Red R.), Tongking [148/1902, p. 187]. Five nearly vertical veins, striking N.N.W. to S.S.E., occur on the right

bank of the river. The veins, covered by a shallow gossan, vary from 1½ to 5 ft. in thickness, and contain carbonate ore followed by unaltered sulphides. To the north on the left bank of the river is the outcrop of a similar vein, 1½ ft. in thickness, and rich in copper. Copper ore outcrops to the south at various places on the left bank, both oxidized and sulphide ores being present in gangues of ochreous schist, quartz (often auriferous), chlorite and dolomite. Quartzose ores assayed 12 to 27% copper; schistose, 18 to 31%; and dolomitic ore, 6%. The average content was about 16% copper. The gold contents varied from a trace to 27 dwt. per ton; the silver, up to 4 dwt. per ton. Saugy thinks the exploitation of these deposits should be remunerative. Copper ores have been found by natives at several places in the province of Tranninh, Tongking, but the deposits have never been exploited [148/1916, p. 776].

Copper mines are worked by natives in the province of Kwang-nam, Annam. Copper ores have been found near Vien-Tiane and at Savanakhet, Laos, and in the lateral valleys of the Mekong River [149].

In 1919 there were nine copper mineral concessions in Indo-China [150].

Recent exports of copper ore from Haiphong, Tonking, are as follow:

	1910.	1911.	1912.	1915.
Metric tons . .	32	29	55	67

[148/1917, p. 409]

Japan and Formosa

Japan.—Copper mining in Japan dates from the year 708, when copper was found in the province of Mushashi. The copper produced was used to a small extent for minting purposes, but mainly for casting bells and images for the temples. Early in the fifteenth century a considerable amount of copper for that time was exported to China, one shipping invoice, dated 1456, showing 92 tons of copper in one cargo. The Dutch did much trading for copper with Japan till the year 1858 [151].

Modern smelting methods were introduced into Japan in 1890 by the late William Gowland, and more recently

Japanese engineers have adopted the latest American practices in handling low-grade ores.

Production of copper has steadily increased during late years. In 1912 Japan became the second largest producer of the world. The copper industry in the country is next in importance to that of petroleum.

Owing to stimulation by the high prices ruling during the war, old mines were reopened. In 1917 owing to the fixing of the price of copper by the allied governments, at which Japan could not produce, her production decreased considerably. After the signing of the Armistice the price of copper seriously dropped, and it became cheaper for the Japanese to buy in the United States than to produce. During the war Japan started extensive manufactured copper and brass industries, which she will want to maintain, so she is likely to be a buyer of copper for some time to come.

Copper deposits are found in all parts of Japan, and about 40 mines were in operation till recently. The deposits of the Ashio mines (Furukawa Co.) are at Ashio in the province of Shimotsuki, and are fissure veins, the largest of which is 3,000 ft. long, 2 ft. wide, and 3,000 ft. deep, occurring in liparite intrusive through Palæozoic slate, sandstone and quartzite. The ores are chalcopyrite and pyrite in a siliceous gangue, but are complex. The Ashio mine is the largest in the Far East, has 190 miles of drives and has been worked in depth to 3,700 ft. It is operated from a remarkable 10,000 h.p. hydro-electric plant. The mine yielded 15,460 metric tons in 1919, the largest output in Japan.

In the Besshi mine (Sumitomo Co.), on the island of Shikoku, Iyo province, bedded pyritic deposits occur in crystalline schists or Palæozoic rocks, such as chloritic or graphitic schists. The ores, pyrite and chalcopyrite, contain about 3½% copper. The largest ore-body is 5,000 ft. long, 4 ft. wide, and 3,000 ft. deep, and dips at 49°. The mine has been in the hands of the Sumitomo family since 1691. Production in 1919 was 10,610 metric tons of copper.

Complex sulphide deposits, which contain about 2% copper with blende, pyrite, galena, gold and silver, and which are replacements in Tertiary sedimentary and in volcanic rocks,

are found in the Kosaka mines (Fujita Co.), in the extreme north of Hondo Island; they were originally worked for silver. The ore-bodies are largely mined by open-cut methods. One is 1,600 ft. long, 400 ft. in maximum width, and 400 ft. deep. In 1919 the Kosaka mines produced 9,022 metric tons of copper.

Contact deposits of great irregularity as to form and size and confined to the margins between Palæozoic clay-slates and limestones, and intrusive granites and diorites, are found in the Kamaishi mines, also in the north of Hondo Island.

Ores from fissure veins and contact deposits are concentrated, the concentrate being smelted in blast furnaces with semi-pyritic smelting, the coke charge being from 8 to 16%. Ores from the bedded and replacement deposits are treated usually by pyritic smelting [152].

Considerable amounts of gold and silver are recovered as by-products from the copper ores of Japan, most of the silver produced coming from copper ores.

The Hitachi mine S.E. of Ashio, in the province of Hitachi, is owned by the Kuhara Mining Co. It yielded 12,346 metric tons of copper in 1919.

The 4 mines, Ashio, Hitachi, Besshi and Kosaka, together, produce over one-half of Japan's output.

Production of copper and the copper trade of Japan for recent years are as follow:

Production of Copper and Copper Trade of Japan

(Long tons)

	London price (electro).			Production.[3]	Imports.	Exports.	Consumption.	Stocks.
	£	s.	d.					
1914	62	5	6	78,700	nil	43,305	32,045	1,500
1915	84	2	7	83,017	324	56,528	27,723	4,873
1916	138	0	10	111,562	2,325	58,432	59,632	536
1917	136	8	10	122,379	14,109	71,052	63,309	2,227
1918	128	5	10	95,455	1,068	31,553	65,397	2,250
1919	100	15	1	81,855	27,570[2]	19,132	67,188	26,800
1920[1]	110	12	10	65,000	22,600[2]	5,000	83,000	25,000

[1] Estimated.

[2] Sudden increase due to home development of water-power undertakings and to increased demand from China for copper for coinage.

[3] Official figures are given in Table on p. 36.

The increase of consumption in 1916–18 was owing to the war; the increase in 1919–20, to the consumption of copper wire for transmission purposes by new hydro-electric power schemes.

Recent costs of producing copper in Japan, calculated at yen = $24\frac{9}{16}$ pence, are as follow:

Costs of Producing Copper in Japan

(Per long ton)

	£ s. d.		£ s. d.
1914 . .	48 10 0	1918 . .	78 0 0
1915 . .	43 6 0	1919 . .	88 8 0
1916 . .	53 15 0	1920 . .	107 10 0
1917 . .	62 8 0		

[153]

The distribution of Japanese exports of copper for recent years is as follows:

Exports of Copper from Japan

(Long tons)

Destination.	1914.	1915.	1916.	1917.	1918.	1919.	1920.[1]
China . .	14,083	1,432	1,490	4,929	7,420	13,692	3,500
British India .	2,444	1,221	86	3,091	2,437	1,375	350
Asiatic Russia .	5,061	29,530	35,244	10,767	139	—	—
Great Britain .	6,813	12,251	14,352	24,587	5,417	452	600
France . .	3,487	3,958	4,175	17,077	8,510	141	100
Italy . .	200	—	—	4,225	4,374	1,859	—
United States .	4,701	7,833	2,920	2,617	37	—	—
Other countries	6,516	297	164	1,957	3,219	1,613	450
	43,305	56,528	58,432	71,052	31,553	19,132	5,000[2]

[1] Estimated.

[2] Not including copper re-exported from bonded warehouses, estimated at 12,000 tons.

[153]

Formosa.—Copper ore is mined in the north of Formosa (Taiwan) principally in the Kinkaseki mine, and also in the Dobunran mine in Karenko Province, and in the Futa mine in Giran Province. The two latter mines were opened recently.

Recent productions of copper in Formosa are as follow:

	1914.	1915.	1916.	1917.	1918.	1919.
Metric tons .	1,875	1,482	1,151	1,008	610	877

KOREA (CHOSEN)

Copper is found in abundance in different parts of Korea, but development of the deposits has been delayed largely owing to absence of transport facilities.

The Suan Concession, granted in 1905, is in Hwang Hai province, Central Korea; in 1908 it was taken over by the Seoul Mining Co. of Denver, Colorado.

The ore deposits of the concession are of the contact-metamorphic type, occurring in limestone around the edges of a granitic batholith, elliptical in shape and roughly 6 miles by 5 miles in its main dimensions. The periphery, known as the Collbran Contact, is about 23 miles in circumference. The intrusion of the granite has uplifted and shattered the surrounding sedimentary rocks, producing intense contact metamorphism. Around the edges of the Contact ore-bodies occur irregularly in the gangue, which is a highly siliceous crystalline limestone, altered by contact action, containing a considerable amount of magnesia and alumina [9/p. 1762]. The ore is invariably associated with faults that have served as passages for hot mineralizing solutions. The valuable metals of the ore, which consists mainly of chalcopyrite with some bornite and tetrahedrite (rare), are mainly gold and copper; bismuth (as bismuthinite), silver and tungsten (as scheelite) also occur in economic quantities; galena, blende and molybdenite, only in small amounts.

As a general rule the gold-copper ores occur close to the contact, whilst those of lead and zinc are farther from it. D. F. Higgins states that there is very little secondary concentration at the Suan mine [154], and J. M. Maclaren, who examined the property in 1915, came to the conclusion that the ore-bodies represent primary sulphide deposits, the upper portions of which have been eroded away [155]. The Suan mine, 650 ft. in depth, is almost worked out.

The Tul Mi Chung is now the principal mine of the Seoul Co. The majority of the ore-bodies are either formed close to a tongue of quartz-diorite, which divides the mine into two portions, or at the flatly-dipping boundary of limestone with overlying schist. The ore-bodies, on the whole, lie near the

falls of quartz-diorite, and, in all probability the ore was deposited in the limestone by metalliferous solutions that followed in the track of the intrusion (Maclaren). The Soctarie ore-bodies near-by consist of a flatly-dipping band of siliceous limestone, in places altered to a quartzite. The average thickness of this band is about 30 ft. It could be quarried and operated in 1916 at a profit, when the reserves were estimated at 2,300,000 tons containing ½ dwt. gold per ton, 0·95% copper and 0·25% tungstic acid.

In the Suan mill (capacity 8,000 tons per month), after the introduction of flotation in 1913, the gold and copper extraction amounted to about 90%, and that of the bismuth to 60%. The average grade of the mill-ore to the end of 1918 was gold, 8 dwt., silver, 0·6 oz. per ton; copper, 0·92% and bismuth 0·08%. The ore treated at the Tul Mi Chung mill (capacity 14,000 tons per month) to the end of 1918 averaged gold, 6 dwt.; silver, 0·5 oz. per ton; and copper, 0·98%. The flotation concentrate contains gold, 25 dwt., silver, 9 oz. per ton, and copper 26%. The copper extraction during 1918 averaged 90·34%, and the gold extraction about 60%.

In 1916 the reserves, not including those of the Soctarie deposits, were estimated at 1,221,000 tons valued at $13,460,000 [9/p. 1762].

There has recently been great development at the Kapsan copper mines, which were bought in 1916 by a Japanese company from its English owners for £300,000. During 1917, 2,000 tons of roughly-refined copper were sent to Japan. The mine is in the South Kankyo province and is equipped with a smelter of 200 tons per day capacity. The Kosho mine is in the Huchang district, in the extreme north of Korea, within a short distance of the Yalu River. Important copper deposits have been discovered in the South Chusa province in Southern Korea, and a refinery is being erected.

Tsingtan has become the centre of a big Japanese export trade since 1915. The exports of ore in 1916 were 34,000 tons.

New Caledonia

Deposits of copper ore, some auriferous, are in New Caledonia principally in the north, in the Diabot Valley and Pam districts. The principal mine is the Pilou, but formerly the Edison mine at Pouembout was the most important. Copper is also mined in association with nickel. Outputs of copper in the colony in metric tons for the period 1908-1912 according to the *Statistiques de l'Industrie Minière dans les Colonies Françaises* (annual) were :

	1908.	1909.	1910.	1911.	1912.
From copper ore . .	108	1,377	1,126	266	—
From nickel ore . .	7,501	[1]	9,030	[1]	11,116

[1] Not reported.

Persia

"A Returned Resident" [156] states that the country of Persia is extremely rich in mineral wealth, but the difficulty of transport has been against its being opened up. No heavy machinery can at present be taken into the interior, as only camel transport is available. The country is rich in copper, but has not attracted capital in the past, mainly on account of import and export difficulties that hitherto had to be combated. One copper mine at least is worked, not far from the Isfahan-Yezd road in Western Persia, the ore being smelted with charcoal fuel. In the Natanz Mts., a little to the north of Isfahan, is a rich seam of copper ore which so far has not been worked.

A number of small copper slag heaps are scattered over the district of Kuhistan, in the province of Kerman. According to G. H. Tipper [157] the copper ore is carbonate and occurs sporadically in the Jurassic slates. He did not see any ore *in situ*. The slags only gave 0·6% copper. The only deposit of any size was discovered by Khan Bahadur Miran Bakhsh, who noticed on the road, 23 miles from Bahramabad, large heaps of slag and ore. The old workings are now abandoned, owing, it is said, to a lack of fuel in the vicinity. The ore

s principally carbonate with a little sulphide, and occurs, according to Tipper, in the agglomerates of the Upper Cretaceous volcanic series. A determination gave 6·2% metallic copper.

Philippine Islands

A number of copper deposits are to be found on the islands Luzon, Malolos, Mindanao, Marinduque, Mindoro, Panay, Masbate of the Philippines, but all are awaiting development with the exception of the Mancayan deposit in Northern Luzon. Prospecting on the islands has practically ceased [158].

In the island of Luzon are to be found veins of enargite and *famatinite*[1] (Cu_3SbS_4) with selenium compounds of silver and copper, in association with the usual secondary minerals [45/p. 175].

Obstacles to mining and smelting copper ore on the islands are numerous and great. There has been no production of copper since the American occupation.

Syria

Copper deposits are found in many parts of Syria, including the following places: in the Vilayet Aleppo, near Aleppo; at Jebel Akra in Beirut and in Beirut Sandjak; at Djebel el Arbain, in Damascus; near Sidon in the Lebanon district and in the Kesrawan district. So far none of the deposits has yet been developed [159].

Timor (Portuguese)

Chalcopyrite is found at Mt. Birogue, west of Baucau in Portuguese Timor. Other copper deposits occur, but all are unexploited for want of capital [52/No. 80, p. 19].

Turkey in Asia

In Turkish Armenia the most important mines are those of Arghana Maden in the vilayet of Diarbekr, where the

[1] A copper-antimony sulphide hitherto found in the Sierra de Famatina, Argentina, and at Cerro de Pasco, Peru.

Turkish government worked 3 out of 6 ancient mines before the war. In the period 1892-1911 there was a total output of 19,000 tons of black copper, produced by 4 small furnaces, which had a capacity of 5 tons of ore per day. It was estimated that there were reserves of 1,200,000 tons of ore, mainly chalcopyrite, containing 15·6% copper. For three years before the war the copper was sold at a profit of £11 10s. a ton [160]. There are other small, often unworked, copper mines in the same neighbourhood.

In the vilayet of Sivas there are occurrences of copper near Sivas town, at Yildiz Zara, at Karahissar, at Amasia and at Tokat. At the last place the copper from Arghana Maden is refined before being sent to Samsun. Several concessions had been granted in Sivas, but no work had been done up to the beginning of the war. Transport difficulties are great in the winter or prospects would be brighter.

Copper is found in small quantities in the vilayet of Trebizond in about a dozen places. In the vilayet of Adana, copper is found at Selefke, 10 miles from the coast. The old copper mines of Kure are in Kastamuni, 15 miles from Ineboli, on the Black Sea, but their output is insignificant. In the vilayet of Bitlis copper ore is worked at Sassun by the natives.

In the vilayet of Erzerum copper ore was formerly mined at Konkez, at Penek, province of Terjan, and at Gobal Kom. There are also copper deposits at Coritza, near Kharput, and at Aidan and Brusa.

In Anatolia at Handek, about 80 miles from Constantinople, is an important deposit consisting of 5 separate beds of schist, impregnated with copper, similar to that at Mansfeld, Germany. The ore is reported to contain 5% copper.

AFRICA

Abyssinia

Prospectors have found evidences of copper and nickel deposits in the Walega Province, and commercial deposits of copper are reported elsewhere in Abyssinia, but up to date none of them has been worked on a commercial scale [161].

Angola (Portuguese West Africa)

Malachite is found at several places in Angola; in a valley near Bembe, in the interior of the Congo district to the south of San Salvador do Congo; also lower down on the Brije River, as well as on the Kuvo River about 25 miles from its mouth. The malachite is often found in solid blocks, but usually in flat veins or beds without any order or dip. These deposits have been mainly worked by natives, who formerly brought from 200 to 300 tons of ore per year to Ambriz. An English company abandoned a concession on the Bembe Valley, after working it for a short time in 1859, when it was again worked by natives.

Later on, copper ore was found at Kwico, in the Benguella district, about 9 miles south of Dombe Grande. The deposit was formed at the bottom of a depression in gneiss.

Small quartz veins with chalcopyrite occur inland from Mossamedes; though rich they are not big enough to work. Copper ore is worked by natives in the interior at Lunda [52/No. 120, p. 68].

Belgian Congo

The physical geography and ethnology, the resources in minerals, agriculture, etc., and the established communications of the Belgian Congo have been described by M. Horn [162].

The territory contains in its S.E. portion, near the Northern Rhodesian border, a large copper belt of about 250 miles in length, east and west, from 30 to 60 miles wide, and at an altitude between 4,000 and 5,000 ft. This belt is under the control of the Union Minière du Haut Katanga, a Belgian company, about one-third of whose shares are held by the English company, Tanganyika Concessions, Ltd.

In the belt are at least 100 known deposits, of which 3 only have been properly opened up so far. These are the Star of the Congo, the Kambove, and the Luushia. Seven other mines, including the Likasi and the Chituru, have been explored by pits and underground work, and much ore has been proved in them.

H. Foster Bain has described the geology of these deposits [163]: the Star of the Congo in the S.E. of the concession is 12 miles from Elizabethville, and was first opened on account of its accessibility. The rocks met with are dolomite, shale, sandstone and quartzite. At the south side is a decomposed mica-syenite, which, it is to be noted, is the only igneous rock reported in association with the ore deposits. The rocks dip very steeply and are arranged in accordance with the following table:

Rock.	Copper	Minerals.	Approx. width.	
	%		ft.	
Disintegrated Quartzite.	17	Malachite .	40	"The green ore"
Indurated Sandy Shale.	8	? . .	30	—
Quartzose Ore . .	5½	? .	30	—
Main Zone . . .	18-20	"Black oxide ore" . .	20	"The black oxide ore"
Quartzite Rib . .	3	? . .	150	—
Dolomite (unconformable) . . .	7½	Black oxide of copper . .	over 200	"Cobalt and copper in black earth"

The Kambove mine is on high ground 100 miles N.E. of Elizabethville. The rocks are quartzite, sandstone, sandy shales and phyllites, dipping 70° at the surface. Lower down the dip modifies and the deposits become more like sedimentary rocks. The mine is very rich, and high-grade ore only is sent to the smelter.

From the Luushia mine, which is 55 miles from Elizabethville, 20,000 tons of self-fluxing ore was removed in the making of a railway cutting. The copper contents of the various layers of ore vary from 5 to 19% and the copper is present as oxides and carbonates, with cobalt and iron as accessories.

"Cupriferous quartzite, sandstone and shale are the ores mainly worked. These are impregnated with copper, mainly as malachite, but azurite and melaconite are also present. With the last is often associated pyrolusite. There are small amounts of chalcocite, and often cobalt. No gold, silver, antimony, arsenic, zinc or lead has been found in the deposits, so the ores are very simple. They resemble those formed by concentration by meteoric waters in sedimentary rocks, without any direct connection with igneous rocks or agencies.

According to Lyon and Keeney [29], experiments were made by Stephen in 1913 on oxide ores of the Belgian Congo, which were smelted in an electric furnace. Analyses of five different samples gave the following percentages and ranges of composition of the ore: Cuprous oxide (Cu_2O), 21·01 to 5·73; silica (SiO_2), 28·48 to 78·55; alumina (Al_2O_3), 4 to 13; ferric oxide (Fe_2O_3), 4 to 16; cobaltous oxide (CoO), 2 to 7; nickel, none. The reducing agents used were anthracite, coke, and charcoal, and the resulting pig copper had the following variations of percentage composition: Copper, 65 to 95; iron, 1 to 21; cobalt, 1 to 11.

At Katanga no systematic search has been made for sulphides, but it is thought, from the little that is known, especially at Luushia, that there are possibly about 7 million tons of 2·3% sulphide ore, of a disseminated character.

At present at Lubumbashi, near Elizabethville, is a smelting plant of 7 water-jacketed blast furnaces to which ore is brought by rail from the various mines. The plant has a production capacity of over 100 tons of copper per day. Both coke and coal are brought from the Wankie Colliery by rail, a distance of 725 miles. The company erected coke ovens in 1912 and has been producing its own coke since 1914 from the coal. The present fuel consumption per year is 100,000 tons, of which 40,000 to 60,000 are coke. There are known coal deposits 600 miles away, but they are at present inaccessible. The flux used for smelting is a dolomitic limestone found near the Star. Black copper is mainly produced by the blast furnaces and is shipped to England for refining.

There are at Katanga immense quantities of low-grade oxide ores, containing about 4% copper and over, which will be treated shortly by a leaching and electrolytic refining plant that is being erected. This plant will have a production capacity of 40,000 tons of copper a year, and will be operated by a hydro-electric plant of 60,000 h.p., for which the falls of Lufira and those on the Lualaba will be utilized. A 4,000-ton per day concentrator at Panda was in partial operation in 1921, producing 20–25% concentrate from low-grade ore.

Outputs of copper in matte and black copper of the Union Minière are as follow:

Year.	Metric tons.	Year.	Metric tons.
1911	997	1917	27,463
1912	2,492	1918	20,238
1913	7,245	1919	23,028
1914	10,772	1920	18,962
1915	14,040	1921	30,470
1916	22,149		

It has been asserted that, when all the proposed extensions are completed, the total output will be raised to 125,000 tons of copper per year, but this is not likely to be the case for some time.

So far, only rich ore containing from 10 to 15% copper has been treated in the blast furnaces, and the residual slag is estimated to contain the high amount of 2% copper.

The ore reserves of the Union Minière are estimated to be 49 million tons, containing 2,830,000 tons copper [55/1921, p. 170].

The cost of producing copper, at the market, in 1918, was £61 7s. per ton [36] [163 to 165].

At Bamanga, near Ponthierville, about 60 miles up the Congo River from Stanleyville, granite and gabbro come up to the surface in small areas in a vast sandstone country. A copper deposit occurs in the granite in a quartz gangue. The ore is chiefly chalcocite. So far the deposit has been opened up for a length of 300 ft. and the ore has been taken out to a depth of 10 ft.

A cupriferous quartz vein, 8 ft. wide occurs at Siku M'Bidi, about 70 miles S.E. of Kasongo. Copper deposits have been reported at Baudouinville, Lake Tanganyika; also between lakes Tanganyika and Kivu. In the Lower Congo chalcopyrite occurs in dolerite, whilst in various parts of the Congo are "copper placers," which consist of thin pebble beds with rich ore. Copper deposits are also known near the junction of the Ubanghi River with the Congo, and between the rivers Lowa and Oso, S.E. of Stanleyville [52/No. 99, pp. 85, 115] [57/No. 1,213, p. 202].

French Equatorial Africa (French Congo)

The M'Boko Songo-Mindouli copper belt of French Congo is immediately north of the Belgian Congo. Copper ore is

mined by the Compagnie Minière du Congo Français, south of the Niari or Upper Kwilu, and is transported to Brazzaville over the company's own railway. Ore was formerly mined on the right bank of the River Jue (Djoué) by the Société des Mines de Djoué.

Production of ore in the country is small, and only rich ore containing about 45% copper is sent away to France.

According to the *Statistiques de l'Industrie Minière dans les Colonies Françaises*, the amounts of copper in the ore exported in recent years were:

	1913	1914.	1915.	1916.	1917.
Metric tons . .	574	652	185	270	75

French West Africa

Copper has been found, but has not been exploited at Bafulabe in the colony of Upper Senegal-Niger [52/No. 107, p. 41].

In the colony of Ivory Coast copper has been found in the districts of Sanwi and Baoule [52/No. 104, p. 25].

Madagascar

In the north of the island of Madagascar there are copper deposits at Vohemar; near Ikalamarony; in the Ivohibe du Sud, and at Lake Kinkony. The first two have been examined and appear worthy of exploitation.

The Colonial Government in association with M. Pachoud are exploring deposits in the Ambositra district, which are in crystalline limestone, mainly to find out if the lodes continue in depth. The work in hand will take two years [166].

Morocco

Copper has been traced in French Morocco on the southern slopes of the High Atlas Mts., and in the Sousbasin are deposits which are worked by natives [52/No. 101, p. 51].

In Spanish Morocco copper ores are being worked in the Rif district [52/No. 122, p. 26].

Copper ores associated with lead are to be found in various parts of Morocco, Tunis and Algeria from which there have been small productions.

Portuguese East Africa

Copper ores have been mined in two distinct regions of Portuguese East Africa; in the Manica district, largely under the control of the Mozambique Company, and in the district of Tete, which is less known. The latter region is an irregularly-shaped area, on both sides of the Zambesi, but mainly north, and contains a number of isolated fields.

The Edmundian mine and others are in Manicaland, a few miles west of Massikissi and close to the Rhodesian border. They were worked till 1910, when they were closed owing to a machinery breakdown. The values of previous copper ore outputs were:

1906.	1907.	1908.	1909.	1910.
£172	£2,583	£3,495	£22,111	£20,585

Ancient copper mines are at the confluence of the Sibi and Lunde rivers.

In the Tete district copper has been found in the Mazoe country; along the Revugo River, near Chikoa; and in the district between Zumbo and Pamba.

There are old workings at Kakanga, in the *prazo* of Marabue, near the confluence of the Revugo and Moatizi rivers; and at Pandamakwa, on the right bank of the Zambezi, between the rivers Messanangue and Chicacoma, where the ore is in beds of crystalline micaceous limestone, overlying beds of micaceous schist, and is in forms of metallic copper, bornite, cuprite and chalcocite.

Copper indications are to be found over a large area at Inyatasango, west of Tete, and also along the Inyambunado River, at Inhondue on the left bank of the Zambezi, opposite Boroma.

A copper-bearing reef in the Morinde *prazo* further up the Zambezi has been traced for one mile. Many old workings are alongside the Mavuzi River on the left bank of the Zambezi. Others are to be found at Panzo; at Pandamaca, in the district between Mezanangwa and Chikoa; and also east of Chiperi [57/No. 1,189, pp. 263, 271].

NORTH AMERICA

CUBA

Active copper mining in Cuba has been carried on until recently by about a dozen companies, most of the deposits occurring in the western province of Pinar del Rio and in the eastern province of Oriente. The industry started with the advent of the Spaniards, early in the sixteenth century. Since the Spanish-American War Americans have been largely interested in copper mining in Cuba, and the exports of rich ore and concentrate are almost entirely shipped to the United States.

According to *Foreign Commerce and Navigation of the United States* (annual), the copper contents of the ore, concentrate and crude copper, all exported to the United States in recent years, were as follow:

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Long tons .	8,339	12,891	18,144	20,243	12,820	7,133	8,235	7,800

The Cuba Copper Co. owns the El Cobre mine near Santiago. This was the first mine in the New World to be worked by white men: it was opened by the Spanish in 1532, and copper from it was used for casting cannon. In 1832 an Anglo-Spanish company took over the mines, and exported much ore to Swansea up to 1869. The ore is obtained from three quartz veins in a mineralized zone, traversing volcanic breccias interbedded with lavas. The ores are pyrite and chalcopyrite, frequently coated with covellite. There are other deposits of less importance in zones of fissuring and crushing in serpentine [45/p. 168]. The oxidized zone is from 50 to 75 ft. deep, and below it are the sulphide ores containing from ¾ to 5% copper. The company owns a 600-ton mill and concentrator, which prepares the ore for a 700-ton flotation plant. About 600 tons of ore a day can be treated to produce 2,000 tons of copper per year [9/p. 1862]. Operations were discontinued in January 1919, on account of the low grade of the ore and of abnormal conditions [10/p. 1760].

The Matahambre mine near the port of Santa Lucia, in the province of Pinar del Rio, is owned by Cubans, has been

developed to a depth of 1,000 ft., and has seven years' reserves of ore. In 1918 about 75,000 tons of ore were shipped. A 1,000 h.p. plant at the coast and a mill on the mine 10 miles inland were recently completed.

The West Indies Mines Development Co. owns the Constancia and other copper mines near Viñales, north of the Matahambre mine.

The province of Oriente produced 13,000 tons of concentrate in the first six months of 1918. Increasing production is expected [167].

Haiti and Santo Domingo

Copper mines have been worked for several years in Haiti.

The Haiti Mines Co. has a concession of 250 sq. miles N.W. of Gonaives. At Menú there is a contact-metamorphic deposit of bornite ore in garnetized Tertiary limestone, which has been invaded and altered by andesite and quartz-diorite, and veins of copper ore are found in the eruptive rock at and near the village of Terre Neuve. There has been considerable surface-stripping of the deposits, and there are numerous shallow shafts and short adits, whilst shipments of sorted ore have been sent to smelters.

According to a British Consular report copper ranks next to gold in importance in Santo Domingo. In the province of La Vega, at Cotuy and Bongo, there is a copper-bearing quartz vein, which seems to be rich, but is undeveloped. There is one copper mine in Asiento Frio, district of Monte Cristi, and another in Rio Arriba section, in the province of Azua. Several lodes are believed to be profitably worked in Mt. Mateo, Rio Nigua, province of Santo Domingo.

The Bucaro mine, on the Rio Nigua, is owned by the Blanton Copper Mining Syndicate. The ore-bodies are in limestone, near a porphyry contact. One ore-body carries chalcopyrite, bornite and chalcocite, all of which are auriferous and argentiferous. The development is by adits, the work aggregating 3,500 ft. in 1917, with 35,000 tons of ore blocked out.

The Ferdinand vein, opened up for 200 ft. on No. 1 level, is said to average 16% copper for a length of 150 ft., and to have 25,000 tons of possible ore. The Santiago vein, from 40

to 80 ft. wide, carries from ½ to 1½% copper along two levels, 200 ft. long and 130 ft. apart. The company was out of funds and the property was idle in 1919 [10/p. 1761].

Honduras

Copper occurs in veins near the Gulf of Fonseca, Honduras, and in the remote mountain sections at Coloal and Olancho copper-silver veins are said to be worked on a small scale by natives for the silver only [55/1919, p. 179].

Copper, gold and graphite are said to occur in a rich deposit of manganese in Puerto Cortes district.

Mexico

The copper-mining industry in Mexico is of old establishment, and the country has always been an important producer of copper, holding the second position in 1911. After that date owing to civil war there was a serious drop in production for three years, which was followed by a revival. This last was owing to the steadily increasing outputs of the American companies in the four northern border states, especially Sonora, which contains the southern extension of the rich copper belt of the south-west of the United States. In the southern states of Mexico, copper-mining is almost at a standstill, and but little information is available at present. Heavy taxes, and serious rises in working costs, due to arbitrary scales of wages, have, in many cases, made mining very difficult. Threats of confiscation by the government, in the case of stoppage of producing mines, have compelled the working only of rich ore, often one-half of the ore being left behind in the stopes.

Aguascalientes

In the state of Aguascalientes at Asientos are the Nopensada and Alta Palmirá mines containing copper ore carrying gold and silver. The ore of the Refugio mine contains up to 10% copper with silver to 36 oz. per ton. The Fortuna, at Tepezalá, contains good silver-bearing copper ore. The country of both districts consists of hornblende-andesite or diorite. At Aguascalientes is the smelter of the American Smelting and

Refining Co. of 2,300 tons daily capacity, which treats ore from the neighbouring states, as well as from Aguascalientes.

Baja California

In the state of Baja (Lower) California the Compagnie du Boleo of Paris owns at Santa Rosalia 11 groups of copper claims of 50,000 acres, containing several important deposits.

The ore-bodies are three bedded deposits (*mantos*) of decomposed tuff, through which copper minerals are disseminated either as concretions, or as thin irregular veins with a clay flucan or gouge. The beds are interstratified with argillaceous tuffs (roof) and conglomerates (floor) which strike N.-S. and dip E. 10° to 15°, and are of Miocene age. The country is traversed by various eruptive rocks, chiefly trachyte. The ore above water-level consists of melaconite and other oxidized copper minerals, containing silver, lead, cobalt, antimony, iron and manganese: below water-level the principal sulphides are covellite and chalcocite. Among the oxidized ores found at Boleo may be mentioned cuprite, atacamite, azurite, malachite, chrysocolla and crednerite ($Cu_3Mn_4O_9$). Several rare oxychlorides, chlorocarbonates and carbonates are peculiar to the deposits. The middle bed carries oxide and carbonate ores in oolitic concretions (*boleos*—hence the name of the mine). The lowest bed of ore, averaging 3 ft. in thickness, is the main source of supply [10/p. 1667] [168].

The company owns twelve 200-ton blast furnaces and produces a matte containing 60 to 65% copper, which is blown in part to over 93% black copper, production being one-third black copper and two-thirds matte. The products are shipped to France or to England. The company has been producing steadily all through the political disturbances, mainly owing to its isolated position. It was producing in 1918–19 at the rate of 759 metric tons copper per month from ore that averaged 3·49%. The 1920 production was about 5,300 tons.

There are other mines in Baja California at Sta. Catarina del Norte, on Cedros Island, at Angeles Bay, and at San Antonio, some of which have shipped ore.

Chihuahua

In the state of Chihuahua there are deposits of copper at Ciudad Juarez, Naica, Terrazas, Las Vigas, Jimenez and Almoloya. Mining is being gradually resumed.

Coahuila

At Jimulco, in the state of Coahuila, the Santa Maria, Sultana and other mines carrying argentiferous and auriferous copper are said to be shut down. In the well-known lead region of the Sierra Mojada certain contact deposits occur which contain copper ores, e.g. in the San José mine, a layer of porphyritic breccia, in contact with limestone, is impregnated with 4 to 6% copper as oxide, associated with chloride of silver [169/p. 555]. The Pánuco copper mine is described as having a large mass of pyrites carrying 2% copper.

At Torreon a smelter company treats its own and custom ores of gold, silver, lead and copper, but has only been operating intermittently since 1914.

Chiapas

In the state of Chiapas, gold-silver-copper deposits were formerly worked at Santa Fé. The ore contained 3 to 4% copper, 6 to 8 oz. silver, and 6 to 30 dwt. gold per ton.

Durango

In the state of Durango the Avino Mines, Ltd., owns mines near Gabriel, including the Socavón, which contains a complex copper-lead ore with gold and silver. In 1913 the reserves were 113,000 tons containing 1·8% copper, 10 oz. silver and 6 dwt. gold per ton. An unsuccessful attempt was made to resume operations in 1918 [10/p. 1687].

The Mineral del Carmen mine, at El Oro, carries silver-bearing copper ores. It is equipped with a milling and concentrating plant.

The Magistral and Cocinera mines of the National Mines and Smelter Co. are at Magistral. The former contains a 1% copper vein, with 1·03 silver and 10 dwt. gold per ton. The latter has a shoot 1,000 ft. long, 15 ft. wide, and has been

developed to a depth of 600 ft. The company has 190,000 tons of reserves and a smelting plant of 6 blast furnaces. It had shipped up to 1918 to the Aguascalientes smelter, 8,000 tons of matte, containing 15% copper, 155 dwt. gold and 8 oz. silver per ton.

The San Luis Mining Co. was developing the 4 old mines, Potosina, San Gonzalo, San Lucas and San Pablo, in the San Lucas and Pánuco de Coronado districts. It possesses a small wet concentration mill [9/p. 1640].

In the Velardeña district some low-grade copper ore was raised at the Copper Queen mine before the war. Silver-lead-copper sulphide ores occur at Los Liberos and other mines in the San Lorenzo range [169/p. 558].

In the eastern part of the state the predominating sediments are Cretaceous limestones and schists, which have been strongly folded, dislocated and penetrated by such eruptive rocks as andesite and rhyolite. At the contact, where the limestone has been metamorphosed into marble, it carries lead ores, but where it has been metamorphosed into wollastonite ($CaO.SiO_2$) and grossularite (calcium-aluminium-garnet), it carries ores of copper, which show no evidence of having been formed by substitution like the lead ores. The copper deposits contain from 10 to 25% copper, with a very low but varied amount of silver, and 4 to 7 dwt. gold per ton [170].

Guanajuato

In the state of Guanajuato the Santa Brigida group at Pozos, Sierra Gorda district, contains ore-bodies, striking N.W.–S.E., which carry copper, lead and silver. The ores are sold to the San Luis Potosi smelter. Copper ores also occur in the district of León [169/p. 564].

Guerrero

In the state of Guerrero the Pacific Copper Co. has been developing for some years the Rey del Cobre group of mines near the Rio Murga, in La Union district, and in 1916 estimated it had 3,000,000 tons of 1·5% ore blocked out. At La Nava mine, district of Guadalupe, the Rio Grande and Dolores Silver

Mining Co., Ltd., till recently, has been working copper-silver ore; the mine is equipped with a 20-ton mill and a leaching plant [9/p. 1649].

At Campo Morado, in the district of Aldama, there is an enormous prism of cupriferous pyrite between black altered schists (floor) and dioritic conglomerate (roof). The lens strikes N. 65° W., dips S.W. 45°, and has been explored by day-levels to a depth of 800 ft. The oxidized envelope or cover appears to be stratified conformably to the slates, which form the floor of the deposit. The average percentage composition of the prism is approximately: Iron, 38; sulphur, 45; silica, 5; lead, 2; copper, 2 [171]. The ore is of primary origin.

Hidalgo

In the state of Hidalgo the Hidalgo Copper Mining and Smelting Co. owns 44 mines of 500 acres area, at Zimapan. The ore-bodies are contact ones, and are estimated to contain 2·8% copper, with 26 oz. silver per ton. The ores are of great variety, containing copper oxides and carbonates, carbonate and sulphide of lead, argentite and chalcopyrite. The company owns a 50-ton smelter [9/p. 1652].

The country is monzonite-porphyry and limestone. The silver-copper veins strike N.-S., are 21 ft. thick on an average, and carry equal values in silver and copper. Veins striking E.-W. carry silver and lead [169, p. 574].

Jalisco

In the state of Jalisco, at San Martin Hidalgo, La Regina Mining Co. has been developing the San Vicente, La Perla, La Fé, La Concha, Ajax and other mines. It is estimated that 125,000 tons of auriferous copper ore have been developed [9/p. 1657].

At Ameca the Magistral-Ameca Copper Co. owns the Mina Magistral containing cupriferous quartz contact veins, on a porphyry dyke, which vary in thickness from 5 to 50 ft. The ore is said to contain 4 to 7% copper. The company possesses a concentrating plant, rebuilt in 1914. In the same district the Mascota Copper Co. owns an old mine, estimated to contain

40,000 tons of 5% ore, with 7 oz. silver and 4 dwt. gold per ton, and a small concentrating mill. An 8-ft. fissure vein in porphyry, traceable for about 2,000 ft., has been proved to a depth of about 500 ft. Other veins near Ameca are in granulite, cut by dykes of diorite and hornblende-andesite, and carry auriferous pyrite and copper sulphides. There are several copper mines in the district of Ayutla. In the district of Autlan are some deposits of chalcocite and malachite, with occasional mercurial tetrahedrite, and others of quartz containing zeolites, chrysocolla and limonite, with disseminated native gold [169/p. 576].

Michoacán

In the state of Michoacán the Ario Copper Co., at Ario de Rosales about 5 miles from Inguarán, owns 320 acres of mineral land containing the old mines, Flora, Roma, Bohemia, San Antonio and San Valentin, carrying copper and silver ores, some rich in copper.

The Inguarán mine at Ario, controlled jointly by the French house of Rothschild and the Banque Mirabaud, and partly owned by the Companie du Boleo, is in the Tacambaro district 70 miles north of the Balsas River, on the plateau of the volcano, Jorullo. A large granodiorite dyke from 2,000 to 3,000 ft. wide, traceable for several miles, contains in bands a disseminated deposit of chalcocite and chalcopyrite. The ore apparently cuts out at a depth of 1,000 ft. It is estimated that between 2 and 3 million tons of ore averaging 3·25% copper have been blocked out. The ore is suitable for flotation-concentration.

Oaxaca

In the state of Oaxaca, about 3 miles from Ocotlán, the Fortuna Mining Co. owns a copper-silver mine, known as the Treadwell Group. The deposit is a fissure vein, 2 to 11 ft. wide, containing 4·5% copper and 6 oz. silver per ton.

The Teziutlan Copper Mining and Smelting Co., which owns the Aurora mine in Teziutlan, Puebla, and Los Ocotes mine in Ejutla, Oaxaca, has a smelter of two 500-ton blast furnaces. The plant has a capacity of 5,400 tons copper per year. The

ine was closed down in 1913, but in 1917 it was reported at preparations were being made for resumption of work)/p. 1668].

Puebla

In the state of Puebla a copper belt occurs, 15 miles in length and 8 miles in width. It is found along the foothills of the Eastern Sierra Madre, in the districts of Teziutlan and Tlatlanquitepec. The ore-bodies form a series of lenses at the contact between decomposed gneiss (hanging-wall) and mica-schist (foot-wall). The general strike is N.W.-S.E. and the dip S.W.35°. The lenses are irregular in course and dip and follow the lamination planes of the schist. Native leaf copper occurs in the mica-schist foot-wall. The average percentage composition of the ore is as follows: Copper, 6; iron, 20: zinc, 7; silica, 35; sulphur, 20; with 3 oz. silver and 1 dwt. of gold per ton.

The Zautla camp lies 40 miles N.W. of Teziutlan; copper ore has been sent from here to the Teziutlan smelter. At San Juan de los Llanos, close to the boundary with the state of Tlaxcala, several copper-gold properties have been in operation, including the Magistral, a copper mine worked by the Spaniards.

San Luis Potosí

The Dolores mine in the state of San Luis Potosí contains large irregular deposits of 1 to 2% copper ore. The normal production of 600 tons of ore per day is smelted at Matehuala [55/1920, p. 173].

Sinaloa

In the Cosalá district, state of Sinaloa, there is the old El Tesoro mine, where a mass of ore is exposed, 5,000 ft. long and from 400 to 1,200 ft. wide. It is said to average 4% copper, 0·5 dwt. gold and 4 oz. silver per ton. A few years ago copper deposits were being opened up in the Choix region [169/p. 614].

Sonora

In the state of Sonora much copper-mining is carried on, principally in the Alamos, Cananea, Hermosillo and Moctezuma

districts. Sonora is the largest copper-producing state in Mexico, its two chief operating companies being the Greene-Cananea and the Moctezuma.

The Greene-Cananea Copper Co. works about a dozen mines in the Cananea Mts. on a large scale, and has extensive concentrating and smelting plants. In 1919, 1920 and 1921 it produced 20,650, 21,836 and 1,023 short tons of copper.

The Moctezuma Copper Co. is working the Pilares mine at Nacozari. The ore-body is an oval shaped brecciated mass of latite, with a major axis of 2,000 ft. and minor axis 1,000 ft., which has been formed by two systems of faults, one coursing N. and S., and the other E. and W. The ore carries chalcopyrite with pyrite; also some bornite, chalcocite and covellite. It is concentrating ore, and contains 3·25% copper. The leached zone is 18 ft. deep and "pay ore" is met with at a depth of 54 ft. The company works seven other mines. In 1920, 11,614 short tons of copper were produced [55/1920, p. 173].

The Cananea copper deposits occur in the Sierra de la Cananea, forming a N.W. to S.E. belt, 6 miles long and 2 miles wide. According to W. H. Weed, eruptive rocks of Tertiary age break through pre-Cambrian granite, and Cambrian quartzite and limestone. There are three main classes of deposits: (1) Deposits containing secondary chalcocite with pyrite, either massive or disseminated along shear zones in diorite-porphyry; (2) contact deposits containing chalcopyrite, pyrite and some blende in a gangue of altered limestone; and (3) disseminated chalcopyrite associated with blende in a diorite porphyry-breccia. In the Capote mine the ore occurs disseminated in diorite-porphyry as well as in the underlying granite. In the upper levels the ore is chiefly chalcocite, but in the granite it is primary chalcopyrite and bornite with massive pyrite. The mine is 1,050 ft. in depth. In the Sierra de Cobre mine the ore is in limestone. Fissures extending from a fault have acted as channels for the mineralizing solutions, making ore along the veins and for a considerable distance into the walls, replacing the limestone by pyrite and chalcopyrite along the bedding-planes. The Cananea Duluth has a long canoe-shaped ore-body about 1,200 ft. in length, and with a

maximum width of 200 ft. It is a neck of diorite intruded in bedded tuffs. The intrusion is shattered, altered and, 200 to 300 ft. below the surface, is impregnated throughout with pyrite and copper minerals. On the 600 ft. level the central portion of the ore-body is unpayable. The average ore carries 2% copper, and good silver and gold contents [10/p. 1726].

The Arizpe Mining Co. owns El Rey de Cobre and other mines. The former has a gossan cap 300 ft. wide and 1 mile long. In depth the ore is chalcopyrite. The formation consists of volcanic and metamorphic rocks traversed by dykes of porphyry and diorite.

In the district of Moctezuma are some important copper deposits. The Washington mine, 12 miles from Huepac, is a copper deposit in porphyry, with gossan at surface. One ore-body, 150 ft. long and 40 ft. wide, averages 6% copper.

In the district of Hermosillo, the Creston de Cobre mines of the Mexican Mining, Refining and Exploring Co., have 36 ft. of copper ore exposed at a depth of 500 ft. In the Lluvia de Cobra mines, copper ores occur with high silver contents [169/p. 621].

Tamaulipas

A copper belt, 20 miles west of Cruz, extends in a S.W. direction for 35 miles. In the district of San José, according to J. F. Kemp, the formation consists of an eroded laccolite of diorite-porphyry, surrounded by middle cretaceous limestone, except to the south, where it has been cut off by older nepheline-syenite, probably along a fault. The diorite-porphyry is cut by a dyke of green tinguaite (allied to phonolite), and dark camptonite (a very basic rock, allied to basalt). The copper-deposits are found in a contact-zone of the eruptive and sedimentary rocks. The blue limestone is sometimes changed to white marble, and is frequently altered to garnet and other lime-silicates. Chalcopyrite and pyrite occur with the garnet: calcite is sometimes present in the garnet-zone, and, here and there, are considerable bodies of magnetite. The limestone is altered to wollastonite (microscopic), diopside and garnet (mainly grossularite and

andradite), associated with vesuvianite, and, occasionally, with molybdenite. Chalcopyrite and pyrite appear as inclusions in the silicates, and as veinlets and coatings in cavities. These sulphides appear to have been one of the later phases of the contact metamorphism. Where they constitute large masses they doubtless replaced the limestone. The San Carlos Co. has spent large sums in development on this belt, and has installed a 200-ton smelter, but the mines have been idle for some years [169/p. 629].

Tepic

In the territory of Tepic the Cuchares Mining Co. owns copper-silver-lead mines, and has a smelter in the municipality of Acaponeta. In Ahucatlán, 40 miles north of the city of Tepic, is the Yaqui copper prospect. The ore is said to average: Copper, 2%; zinc, 24%; gold, 1½ dwt. and silver 10 oz. per ton. A silver-lead-copper vein, 3 to 4½ ft. thick, occurs due N.E. of the city of Tepic.

Vera Cruz

The mining district of Tatatila and Zomelahuacan is 7 miles from Jalapa, the capital of Vera Cruz. According to Richter and Hübner, the lodes occur most frequently in limestone, rarely in greenstone and porphyry, and never in trachyte. They course N.-S., dip at a steep angle, and are 3 to 6 ft. thick. Veins containing copper ore course very irregularly, and contain auriferous chalcopyrite and bornite. La Concepción lode, which is distinct from the above, contains auriferous quartz, lead, silver and copper ores, and is among the most important [47/p. 864].

Zacatecas

Concepción del Oro is a mining town in the state of Zacatecas at an altitude of 6,840 ft. and a few miles east of Mazapil. It is now known as Aranzazú. The mines of the region may be divided into two groups: (1) the eastern group, including the Cabrestante, Catarroyo, Promontorio, Las Animas, and El Carmen mines; and (2) the western group, the Aranzazú. Both groups consist of cupriferous contact deposits, but that

of Aranzazú is the more important. According to Burckhardt, granodiorite here forms the central portion of a great fold, which is inclined to the east. Westward the mass narrows to a width of barely 1,000 yds. The numerous copper deposits occur along the limit of the western contact with limestone containing *Nerinæa* (Mesozoic). The contact-zone seldom exceeds 300 ft. in width. The primary ore is chalcopyrite, accompanied by a little tetrahedrite; it begins to replace the rich secondary sulphides (chalcocite, bornite, etc.) at a depth of 250 ft. from the surface.

Alfred Bergeat has fully described the geology of the neighbourhood [172].

The Mazapil mineral region was discovered in 1530. The Mazapil Copper Co., Ltd., acquired the old mines of Concepción del Oro about 1891, and since then has established several new ones, and now owns a railway, a 160-ton concentrating plant, and two smelters, one with fine copper furnaces. Operations, suspended in 1913, were partly resumed in 1917, and in 1920 the production of copper amounted to 4,200 metric tons [55/1920, p. 173].

Mexico exports almost all her output of copper. Recent productions are as follow:

	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Metric tons .	20,598	28,411	50,986	70,223	56,172	46,057	15,228

NICARAGUA

In the Pis Pis district of Nicaragua andesite is cut by dolerite dykes and numerous quartz veins. The main vein-system strikes N.-E., dips N.W. 25-75°, contains gold and silver and a complex mixture of copper, lead and zinc sulphides.

The Santa Rita gold-copper mines in the district are worked by the Tonopah Nicaragua Co. Diamond-drilling prospecting was completed in July 1918, and work to 1920 developed 1,492,000 tons of carbonate and sulphide ores, assaying 1 dwt. gold per ton and 5% copper. Work has been suspended until it is practicable to erect a mill, for which tests have been made [10/p. 1757].

Porto Rico

Several copper deposits are known in Porto Rico, some of which were prospected 75 years ago. La Abundancia mine, near Rio Blanco, was opened in 1869. It produced a small quantity of rich oxidized ore from a pay-streak, from 8 to 15 in. thick, carrying bornite and chalcopyrite of average content 10 to 12% copper, in a vein of cupriferous pyrrhotite from 6 to 10 ft. in thickness. It has been idle for several years [10/p. 1762].

Copper deposits are found in the centre of the island at an altitude of 1,050 ft. in the foothill porphyry of a diorite mountain. There is a zone of volcanic breccia striking N. 20° E., and a second belt trending N.-W. and dipping 40° S.W. The fragments of the breccia are cemented by chalcocite and cuprite. The zone is 15 ft. in width, and has been exposed for 100 ft. by open cuts and tunnels. Samples cut 2 ft. deep averaged 3% copper, and a 200-ton shipment to New York gave a 5% smelter return [55/1919, p. 170].

Salvador

According to a table compiled by Rafael Reyes, chief of the Bureau of Statistics of Salvador, there are 4 copper mines in the department of Santa Ana, and 3 in the department of Chalatenango, or a total of 7 in the whole republic [173].

United States

Copper was first discovered in the United States at Massachusetts in 1632. It was first mined at Granby, Connecticut, in 1705. The Lake Superior mines, opened in 1844, were the chief producers until 1883, when the mines of Montana and Arizona became more prominent. The "Porphyry-Copper" era began in 1904.

Originally the only mines worked in the country were in the Appalachian region; of these only those at Ducktown, Tennessee, which date from 1850, are now in operation.

Practically all copper mining at present, excepting that at Lake Superior, is carried on in the region of the Rocky Mts. and its extension through the arid regions of the South-West.

The principal copper-producing states, besides Alaska, are Arizona, New Mexico, Utah, Montana, Nevada, Michigan and Tennessee. California, Idaho and Oregon are comparatively small producers.

W. H. Weed estimated that of the output of North America in 1913, 58% was derived from ores containing chalcocite as principal mineral, 7% from enargite ores, which are almost peculiar to the United States, 20% from the native copper ores of Lake Superior, and 15% from chalcopyrite ores of Nacozari, Sudbury, California and Tennessee.

The great growth of copper production in the United States is illustrated in the diagrams on pages 37 and 40.

Recent average annual prices of copper in New York in cents per pound compared with those in London in pounds sterling per long ton of standard copper are given on page 22.

Average annual prices of manufactured copper for recent years in cents per pound were (f.o.b. mill):

	1916.	1917.	1918.	1919.	1920.
Copper wire . c. per lb.	31·61	33·87	27·85	22·09	22·21
Copper sheet . ,,	37·10	38·19	33·30	28·37	28·26

Substantially all the large copper mines on the American continent temporarily stopped producing copper in the spring of 1921 on account of the state of the market and the accumulation of stocks [174]. The chief companies which ceased operations were the Utah Copper, Ray Consolidated, Chino, Nevada Consolidated, Phelps-Dodge Corporation, Calumet and Hecla, North Butte, and Old Dominion. Large American companies remaining in operation were the Miami, Kennicott (Alaska), Chile Copper and Cerro de Pasco (Peru). These produce about 20,000 short tons of copper per month. On

December 31, 1921, stocks of refined copper in the United States were 248,000 short tons, and there were also in transit and being refined 148,500 tons, a total of 396,500 tons. The normal surplus is 250,000 tons [175].

Tables showing (1) Smelter production; (2) Production, stocks, imports, exports and consumption; and (3) Distribution of exports of copper of the United States for recent years are given on pages 161, 162 and 163 respectively.

The following figures of production, sale price and cost relate to the chief copper producers of the United States for three recent years, and are based on figures which appeared in the *Statist* (May 28, 1921). [*See* p. 19.] The following mines are included: Anaconda, Utah, Ray, Nevada, Chino, Miami, and Copper Range; but Anaconda is excluded from the sale price and cost:

	Production.	Sale Price.	Cost.
	Long tons.	Cents per lb.	Cents per lb.
1918 . .	358,290	23·14	14·52
1919 . .	204,007	18·29	14·93
1920 . .	209,462	17·55	15·01

In 1920, the cost at Miami was only about 12 cents per lb., as compared with 14·83 and 15·81 cents in 1918 and 1919 respectively. The drop in cost was largely due to the adoption of a caving system of mining, whilst economies were also effected in milling and general administration. In Michigan copper was produced on the Mohawk in 1919 at 9 cents per pound.

American Copper-mining Groups

The leading American-controlled mines may be divided into 4 groups according to ownership and control as below:

Ryan-Rockefeller Group controlling Anaconda, Inspiration, Greene-Cananea (Mexico), with an annual capacity of about 220,000 tons of copper.

Smelter Production of Copper in the United States by States[1]

(In 1,000 lb.)

State.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Alaska	24,986	70,695	113,823	84,759	67,082	56,535	66,091	76,808
Arizona	382,450	432,468	694,847	719,030	709,522	536,515	552,989	155,166
California	29,784	37,658	43,401	44,934	44,151	23,549	11,822	15,907
Colorado	7,310	7,272	9,536	10,055	7,592	4,803	4,283	6,593
Idaho	5,875	6,218	7,240	6,446	5,837	3,007	1,922	1,971
Michigan	158,910	238,056	260,795	268,508	231,046	177,504	153,484	100,918
Montana	239,800	298,293	352,140	279,226	320,427	170,260	177,744	49,171
Nevada	60,123	67,757	100,817	115,028	100,207	64,084	55,580	15,129
New Mexico	64,205	62,817	79,863	107,594	99,500	60,377	52,169	18,077
Tennessee	18,661	18,205	14,559	16,094	15,054	15,629	16,728	—
Utah	160,500	175,178	232,336	227,840	230,965	143,830	110,358	45,831
Other States	1,331	2,522	9,487	9,600	7,081	22,550	5,897	20,015
Totals	1,150,137	1,388,009	1,927,850	1,886,120	1,908,534	1,280,419	1,209,061	505,586

[1] *U.S. Geol. Survey.*

Production, Stocks, Imports, Exports and Estimated Consumption of New Copper in the United States [176]

(In 1,000 lb.)

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.[1]
Smelter output from domestic ores	1,150,137	1,388,909	1,927,850	1,886,120	1,908,534	1,286,419	1,209,061	505,586
Refinery production of new copper from domestic and foreign ores	1,533,781	1,634,204	2,259,387	2,428,546	2,432,385	1,805,307	1,634,909	1,020,027
Total stocks of refined, blister, and other copper at the end of the year, at smelters and refineries	376,708	356,430	552,055	525,000	742,600	904,000	1,124,000	783,000
Total imports[2]	306,890	308,162	452,126	538,093	573,675	424,814	469,877	343,784
Total exports[2]	840,081	683,786	789,791	1,132,833	747,689	516,629	624,061	628,807
Domestic consumption	702,000	1,137,000	1,479,000	1,395,000	1,662,000	915,000	1,054,000	611,000

[1] *Min. Indus.* 1921.

[2] *Foreign Commerce and Navigation of the United States.*

Distribution of Exports of Refined Copper from the United States[1]

(In 1,000 lb.)

Country.	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Belgium	—	—	—	—	—	28,090	26,620
Canada	12,221	41,900	49,868	33,087	19,781	20,697	7,199
Denmark	—	—	—	—	—	7,623	—
France	114,296	318,137	369,231	265,270	80,189	118,489	98,732
Germany	—	—	—	—	6,831	89,195	233,072
Italy	43,925	98,249	152,998	121,008	65,344	918	16,370
Japan	—	—	—	—	—	82,014	59,170
Netherlands	—	—	—	—	—	34,228	28,647
Russia in Europe	24,412	45,342	71,050	—	—	—	—
Sweden	18,743	17,309	2,229	8,331	34,341	34,566	8,755
United Kingdom	70,909	173,894	372,743	251,896	105,029	99,480	62,335
Other countries	15,915	22,616	15,051	15,036	135,741	26,027	55,217
Totals	300,411	716,617	1,030,779	690,028	438,161	551,227	596,117

[1] *Foreign Commerce and Navigation of the United States* and *Monthly Summaries.*

Hayden-Jackling Group controlling the "porphyry" properties, Utah, Chino, Ray, Nevada Consolidated, with an annual capacity of about 185,000 tons.

Guggenheim-Morgan Group controlling Kennecott (Alaska), Braden and Chile Copper companies (Chile), with an annual capacity of about 90,000 tons.

Phelps-Dodge Group controlling Copper Queen, Detroit, Moctezuma (Mexico), Burro Mountain and Arizona Copper, which, with ores purchased and treated on toll, has a yearly capacity of about 110,000 tons.

The above totals together account for about 40% of the world's average output [34/1922, p. 76].

"The Porphyries"

The "porphyry" companies include the Chino Copper Co., the Inspiration Consolidated Copper Co., the Miami Copper Co., the Nevada Consolidated Copper Co., the New Cornelia Copper Co., the Ray Consolidated Copper Co. and the Utah Copper Co., and are referred to later.

These companies had in 1918 a daily output of 89,000 tons of ore and produced over 322,000 tons of copper in the year. This was 34·5% of the total output of the United States.

The mines are found in fractured or altered porphyry or schist. The primary ore is unprofitable, except in the case of the New Cornelia mines at Ajo, Arizona, seldom containing over 0·5% copper. It is mineralized with disseminated pyrite and chalcopyrite. There is usually a gossan from 150 to 500 ft. thick, either barren, or with a little copper near the chalcocite enrichment horizon, which varies from 75 to 500 ft. in thickness, averaging 300 ft. [177].

Disposal of American Copper Output

The output of the chief American and American-controlled mines in 1919 was dealt with as follows:

Selling Company.	Disposing of the outputs of
American Smelting and Refining Co.	Utah Copper; Kennecott; Braden; Nevada Consolidated; Ray Consolidated; Chino; Cerro de Pasco; Chile Copper Co
United Metals Selling Co. . .	Anaconda (with N. Butte); Inspiration; Greene-Cananea; Arizona Copper Co.; New Cornelia; Utah Consolidated.
Phelps, Dodge & Co. . .	Copper Queen; Detroit; Montezuma; Burro Mountain; Calumet and Arizona; United Verde Extension; Old Dominion
Calumet and Hecla	Calumet and Hecla; Osceola; Tamarack; Ahmeek; White Pine, Isle Royale, etc.
Lewisohn & Sons.	Miami; Shattuck Arizona.
W. Parsons Todd.	Quincy; Copper Range; E. Butte.
Direct sales by .	U. S. Smelting Co.; United Verde; Copper Range; Quincy; Mohawk; Wolverine.

[34/1921, p. 103]

Alaska

The territory of Alaska was bought by the United States Government for $7,200,000. In 1916 the output of copper alone was worth $28,000,000. Mining is carried on principally in the districts of Copper River, Prince William Sound and Ketchikan in S.E. Alaska.

In the Copper River district the Alaska Copper Corporation is developing a large bornite deposit to a depth of 300 ft. on Nugget Creek, Kuskulana Valley. The Kennecott Copper Corporation, which also owns the Braden mines in Chile and is largely interested in the Utah Copper Co., is developing and mining several large properties, including the Jumbo, Bonanza and Mother Lode. The bulk of the ore is concentrated, and 53% concentrate with an 86% extraction is obtained. Tailing is leached with ammonia. In 1919 an amount of 20,350 tons of copper was produced.

In the Knight Island prospects, King William Sound, the economically copper-bearing minerals are chalcopyrite and chalmersite ($CuFe_2S_3$) which are found intimately associated. The latter mineral is a rare copper-iron sulphide [178].

A large amount of development work has been carried on in Alaska recently. The 1921 production was 28,107 short tons.

Arizona

The state of Arizona in 1920 produced over 45% of the total output of copper in the United States.

The ore deposits of the south-western states have been fully described by the late W. L. Tovote [179]. They mainly occur in a mountain region passing through the centre of Arizona in a N.W. and S.E. direction. This region extends into the S.W. part of New Mexico, the N.E. of Sonora and the N.W. of Chihuahua, these extensions all containing important copper deposits. In the northern part of the region are the important districts of Jerome, Mayer and Prescott. The first contains the mines of the United Verde Copper Co. (U.V.) and the United Verde Extension (U.V.X.), which normally produce about 4,500 tons of ore per day. The ore is solid pyrite and chalcopyrite either in lenses or in veins. The gossan, 160 ft. deep, contains gold and silver with oxide copper ores. There is some chalcocitic enrichment. The original ore contains from 15 to 32% sulphur: it is smelted to an 18% matte Jerome on an average produces about 75,000 tons of copper per year. The Jerome type of ore-deposit persists in the same schist country rock in a belt over 50 miles long.

In the Mayer district are the Yager, Arizona Binghampton, Blue Bell and De Soto mines. The last two usually concentrate and smelt, at the Humbolt Smelter, 10,000 tons of 3·3% ore per month.

The Central Area, the most important part of Arizona, contains the districts of Pinal Mt., Clifton-Morenci, Tuscon, Dragoon Mts., and Bisbee.

In the Pinal mountain region are the large disseminated deposits worked by the Inspiration Consolidated Copper Co. the Ray Consolidated Co., and the Miami Copper Co., which normally mill over 35,000 tons of ore per day. Recent outputs of copper, in short tons, have been:

	1918.	1919.	1920.
Inspiration Cons. Co.	49,320	38,500	39,625
Ray Cons. Co. .	44,300	23,582	24,706
Miami Copper Co. .	29,204	26,300	27,561

There are many other important but smaller mines operating in the district, which can produce about 150,000 tons of copper per year. The Old Dominion Co. has mined from a vein and smelted 1,500 tons of ore per day at its own smelter at Globe, producing 18,000 tons of copper per year: its 1920 production was, however, 11,400 tons.

The flotation process has largely aided the development of the industry in the district, and is used by the Inspiration, Miami, Old Dominion, Arizona-Hercules, and Magma companies.

There are three main classes of deposits: (1) *Disseminated deposits*, in the Inspiration, Miami, Ray Consolidated and Arizona Hercules mines; (2) *veins*, in the Old Dominion, Ironcap, Arizona Commercial, Magma and many smaller mines; and (3) *replacements in limestone*, in the mines of the Gila Sulphide, Gila Cañon Consolidated and London Arizona companies. There are about 250,000,000 tons of ore reserves of 1·6% copper content in the replacement deposits.

In the Clifton-Morenci district, the oldest camp in Arizona, are the mines of the Arizona Copper Co., Ltd., the first company to work a disseminated low-grade porphyry deposit, and the first company to try the leaching of oxidized copper ores. It has a milling and concentrating capacity of nearly 4,500 tons a day with a productive capacity of 30,000 tons of copper per year. The company has been recently merged with the Phelps-Dodge Corporation. In the Clifton-Morenci district are operating the Detroit Copper Co., which can produce between 7,500 and 10,000 tons of copper, and the Shannon Copper Co., about 5,000 tons of copper per year. The district could produce 40,000 tons per year.

All the deposits in the Tucson district are contact-metamorphic deposits in Palæozoic limestone. The mines are all worked by small owners and the grade of the ore varies from 4 to 7%. The usual annual production is about 250,000 tons of ore.

The Dragoon Mts. district contains a large number of mines, which produce about 150,000 tons of 4½ % ore per year.

The Bisbee district at an elevation of 5,000 ft. is in the S.E. part of the state, near the Mexican border. The ore-

bodies are nearly all replacements in limestone, the ore being found in large lenses, some lean and primary and some enriched. The principal companies at work are the Copper Queen, Calumet and Arizona and Shattuck Arizona. The district can produce about 100,000 tons of copper per year from 2,000,000 tons of ore. At Sacramento Hill a large disseminated ore-body is being opened up, and a supply of 4,000 tons of ore per day will eventually be available.

In the Ajo district of Pima Co. is the disseminated "porphyry" deposit of the New Cornelia Copper Co., containing primary chalcopyrite and some bornite in monzonite-porphyry, surrounded by rhyolite and igneous rock. Superficially nearly the whole of the copper sulphide has been oxidized to carbonate, forming a capping above the sulphide ore of 12,000,000 or more tons containing 1·65% copper. The oxidized ore is treated by acid leaching, and the sulphide ore is amenable to flotation concentration. A total of 40,000,000 tons of ore was proved by test-pits 50 ft. deep, and by diamond drill-holes from 200 to 1,000 ft. deep, before the plant was erected. In 1919, the mine output was 5,000 tons of ore daily, but plans have been made for an ultimate capacity of 15,000 tons daily [55/1919, p. 159]. The 1920 output of copper was 20,052 tons.

California

The most important copper-producing districts of California are Calaveras, Placer and Plumas counties.

The Engels Copper Co., operating the Engels and Superior mines in Plumas Co., in 1920 treated 230,612 tons of 2·21% ore by concentration-flotation, and recovered 4,285 short tons of copper, 1,218 oz. gold and 119,165 oz. silver. The 1920 copper output was 4,285 tons.

The Mammoth Co., at Kennett, Shasta Co., is another important producer [180].

Many copper deposits occur in the Siskiyou range. That of the Blue Ledge mine in the Applegate district is of solid pyrite containing chalcopyrite and pyrrhotite. It has been opened vertically for 800 ft. and was being extensively developed in 1919 [55/1919, p. 170].

Colorado

The copper production of Colorado is small and comes mainly as a by-product in the smelting of gold-silver ores. Copper ores are produced and shipped from the Rico and Chaffee districts. In the 5 years to and including 1918 the annual output of the state was about 4,000 tons: it was 2,446; 2,146; and 1,830 short tons in the years 1919–21 [55].

Idaho

The copper output of Idaho comes from a large number of small mines, the bulk coming from those of the Empire Copper Co. at White Knob, near Mackay. Other producers include the Copper Basin, Ramshorn, Anderson and some in the Cœur d'Alene district [55/1917].

On Cuddy Mt., Washington Co., the Idaho Copper Co. is developing a deposit of disseminated copper and magnetite in altered monzonite. An adit has proved the ore to be 350 ft. wide at a depth of 600 ft. The ore averages 1% copper and 50 oz. silver per ton, and has a low gold content. It has been decided to develop the ore-body and to install a flotation plant.

About 40 miles north of the Cuddy Mt. property, the Red Ledge disseminated copper deposit is being developed [55/1919, p. 162].

Michigan

Copper mining began in the state of Michigan in 1844, the copper being found in the central part of the Keweenaw peninsula, Lake Superior, where there is a thick series of copper-bearing conglomerates, sandstones and beds of lava, which at the upper surfaces of the flows are vesicular and known as "ash beds." The vesicles contain native copper and other minerals, and these portions of the lavas are known as lodes or amygdaloids. In the conglomerates the copper occurs between the quartz-porphyry pebbles forming them. Masses of native copper up to 400 tons in weight have been found.

Michigan in 1919 was the second, and in 1920 the third largest producer in the United States. The Calumet and

Hecla group usually contributes about two-thirds of the total production of the state.

In 1920 the outputs of copper in short tons of the principal mines were: Calumet and Hecla, 21,745; Champion, 8,476; Ahmeek, 10,245; Isle Royale, 5,311; Mohawk, 5,135. The outputs of copper in pounds per ton vary from about 17 on the Quincy to about 36 on the Champion: that of the Calumet and Hecla is about 20 lb. per ton.

Milling followed by wet concentration is the ordinary method of treating the ore, and recently the tailing in Torch Lake has been dredged and successfully retreated, the sand by an ammonia leaching process, devised by Benedict, and the slime by flotation. The most important new development in the Keweenaw peninsula is the cutting of amygdaloidal ore at a depth of 1,670 ft. in a section long considered to be outside the zone of the peninsula.

In a report made by J. R. Finlay for the State Tax Commission of Michigan in 1911 it was stated that the amount of recoverable copper in the ore reserves of 14 profitably-producing mines, was 1,340,000 tons.

Montana

The state of Montana has been the second largest producer of the United States. Nearly the whole of the output comes from the Butte district, in which the Anaconda Copper Mining Co. is the largest operator, producing about nine-tenths of the total.

Operations of the company which include the treatment of custom ore were greatly reduced in 1920, largely owing to the drop in the price of copper, to labour troubles and to shortage of coal, the production being 77,670 short tons, as compared with 136,461 in 1918. In 1921 it was only 24,049.

The Potomac Copper Co. is developing well-defined veins in quartzite, near Potomac, N.E. of Missoula. The deposit, known as Copper Cliff, contains particles of famatinite [55/1919, p. 167].

Other operating companies in the state, of minor importance, are the North Butte Co., the East Butte Co., the Davis Daly Co. and the Butte and Superior Co.

Nevada

The most important copper-producing part of the state of Nevada is the district of Ely, where the principal producers are the Nevada Consolidated Co., and the Consolidated Coppermines Co. These produce about nine-tenths of the state's output: the balance comes from mines outside the Ely district. The Boss mine in the Goodsprings district has a complex ore containing 7% copper, 4% bismuth, 1 oz. platinum and palladium, 3 oz. silver and 16 dwt. gold per ton. In the same district are the Red Streak, Oro Amigo and other small mines.

In 1920 the Nevada Consolidated yielded 24,156 short tons of copper compared with 22,985 in 1919. An operating loss of $135,029 is reported for the first six months of 1921, and a total net deficit of $285,492. The reserves in 1920 were given as 63,800,000 tons containing 1·58% copper. Up to the end of 1920 the total output was 380,000 tons of copper.

At the Copper Basin mine, near Battle Mt., the ores are of the disseminated or porphyry type, occurring in a maze of dykes of monzonite porphyry like that at Ely, Nevada, cutting through Palæozoic limestone, argillites and quartzite. Though oxidized ore occurs in veinlets and workable masses, the rich ore rests on the secondary "glance" (chalcocite) ores, which occur at an average depth of 100 ft. and are about 100 ft. thick. The ores carry an average of 2·3% copper [55/1919, p. 169].

New Mexico

In the S.W. portion of New Mexico is the S.E. extension of the Mountain Region of Arizona, which contains the mining districts of Santa Rita, Lordsburg, Deming and Rincon.

The ore-bodies in the Santa Rita district are associated with quartz-monzonite and quartz-monzonite porphyry intrusions (post-Cretaceous), which cut the limestones (Carboniferous), sandstones and shales (Cretaceous), but which are older than the tuffs, rhyolites and andesites (Miocene) of the region. Near the ore-bodies the rocks show marked altera-

tion. The ore consists of chalcocite with some metallic copper and cuprite. The primary ore is chalcopyrite [181].

At Santa Rita the Chino Copper Co. is working an old mine, dating from 1800, which contains a disseminated low-grade porphyry deposit, that has been secondarily enriched. The company usually concentrates over 10,500 tons per day, obtaining a 63% extraction on 1·63% ore, and has about 105,000,000 tons of reserves. In 1920 an output of 22,025 short tons of copper was produced by the company's smelter at a cost of 14·4 cents per pound. The total production of copper, to the end of 1920, was 255,000 short tons.

The Burro Mountain Copper Co. operates a porphyry mine, about 20 miles west of the Chino mine, and can treat about 1,500 tons of 2% ore per day with a 70% extraction.

The "Red Beds" of New Mexico, of Permian age, contain fossil plant remains on which copper is sometimes precipitated. Various oxidized copper minerals are found, and sometimes chalcopyrite and bornite. Pyritic deposits in schist and contact deposits in limestone are known, but have not yet been prospected in depth [179] [182].

Oregon

In 1920 the copper output of Oregon was 1,265 short tons as compared with 1,319 in 1919, and 137 in 1921.

The Iron Dyke mine (depth 850 ft.) at Homestead is the principal copper producer. It is an old mine which was reopened in 1915. The ore is concentrated by flotation [55/1920, p. 163]. The mine was closed down in 1921.

Tennessee

In 1921 the production of copper in Tennessee amounted to 7,542 short tons as compared with 8,360 in 1920. The entire output comes from two large copper mines in the Ducktown district—the Tennessee Copper Co. and the Ducktown Sulphur, Copper and Iron Co. Deeper development in the mines of the latter company has proved the ore-bodies to be widening and to maintain their average copper content. The ore is a mixture of chalcopyrite, pyrrhotite, pyrite and heavy

silicates, and is being concentrated in a differential flotation mill.

In 1919 the Copper Pyrites Corporation started work on the School Section property, on which diamond-drill exploration has developed a large tonnage of low-grade copper-pyrrhotite ore, expected ultimately to amount to 12,000,000 tons [55/1919, p. 171] [183/1920].

Utah

The chief producer in the state of Utah is the Utah Copper Co., operating at Bingham, and yields about four-fifths of the total production. Other less important operating companies in Utah are the Ohio Copper Co., the Bingham Mines Co., and the Utah Consolidated Mining Co.

The Utah Copper Co., one of the "porphyries," possesses the largest developed ore-body in the world, next to Chuquicamata, in Chile. The ore-bodies are altered siliceous porphyry with finely-disseminated mineral. The primary mineral is chalcopyrite, but as a result of oxidation of this, followed by secondary enrichment with chalcocite, a zone of profitable concentrating ore has been formed. About one-third of the oxidized ore is profitable enough to be leached with sulphuric acid. In 1920 the company milled and concentrated 5,556,800 short tons of 1·16% ore, producing 50,949 short tons of copper at a cost of 13·1 cents per pound. At the end of the year the ore reserves were 364 million tons, averaging 1·35% copper. The total copper production to the end of 1920 was 773,000 short tons.

Vermont

In 1919 the production of copper in Vermont amounted to 291 short tons, most of which came from the Elizabeth mine of the Vermont Copper Co., near South Strafford. The crude ore contains 2·25% copper. The mine and mill were closed early in 1919 [183/1920].

Washington

The small output of the state of Washington is won mainly in the Chewelah district, north of Spokane.

The principal mines are the United Silver-Copper, Loon Lake, and High Grade, all in Stevens Co., and the Sunset in Snohomish Co.

SOUTH AMERICA

Copper has been found in all the states of South America, with the exception of the Guianas and Ecuador (*see* p. 193). The great majority of the deposits occur on both the eastern and western slopes of the High Cordilleras or Andes, particularly in Chile, Peru and Bolivia. Many important deposits have been formed by replacements, particularly of limestone. The chief sulphide mineral is chalcopyrite, but chalcocite, bornite and tetrahedrite are common. The important oxidized minerals are atacamite, brochantite, chalcanthite and kröhnkite ($CuSO_4.Na_2SO_4.2H_2O$) which are found in abundance in the desert regions of Chile. Native copper is common in small quantities in the oxidized zones. At Corocoro, Bolivia, it occurs as the chief mineral, being disseminated through grey sandstone. Probably the majority of deposits that are being worked have been secondarily enriched.

Copper mining is an old industry in South America, but was not important until the beginning of the nineteenth century with the development of the Chilean mines, and later with those of Peru and Bolivia. At present South America is second only to North America in amount of production.

The tardy development of many of the copper-bearing districts in South America is due to various causes, the principal being lack of railway communication, of capital, of fuel, and of labour, as well as the instability of the governments. Publication of mining and geological information by various governments is increasing and becoming helpful in the opening-up of the copper deposits of the countries.

ARGENTINA

A large area, mineralized with copper, occurs in Argentina, and is confined to the western portion of the state, north of latitude 35° S. The deposits occur in the most inaccessible part of the republic on the eastern slope of the Andes and on the foothills. Besides the difficulty of lack of transport, there is scarcity of fuel and of water, and as the altitude is usually high Indian labour only can be utilized: of this there is a very limited supply.

Argentina, for the reasons stated, has never been a large producer of copper, and the output in any single year has rarely exceeded 2,000 metric tons. From 1910 to 1913, inclusive, the average was only about 448 metric tons per annum. Since 1913 no regular statistics appear to have been published, but in 1918 copper ingots were exported to the value of $267,118 (U.S.) [55/1918, p. 175].

The principal deposits are veins, found in Palæozoic and pre-Cambrian crystalline rocks, sometimes in the older sediments and in volcanic rocks. Gold-bearing gossans, containing oxide and carbonate copper minerals, are common.

The two most important districts are the Famatina in La Rioja province, and the Capillitas in the province of Catamarca. From the lode deposits of these two districts the greater part of the output of the country has been won.

Los Andes.—In the province of Los Andes, the Concordia mine, at San Antonio de Los Cobres, has complex ore in veins in conglomerates, consisting of tetrahedrite, chalcopyrite, galena, blende and pyrite. The ore is silver-bearing. In some of the veins copper is subordinate to silver.

Salta.—In the province of Salta, in the Acay district, there are veins of chalcopyrite and galena carrying silver, in the southern spurs of the Cerro Nevado de Acay. The country rock is granite and trachyte or andesite.

Catamarca.—The Capillitas and Atajo districts are in the Sierra de Aconquija, and the Hoyada district in the N.W. of the province of Catamarca. The veins of the Capillitas district cross a N.–S. contact of porphyry and gneiss. The best mines are in porphyry. The Restauradora mine has

been worked by an adit to a depth of 800 ft. below the outcrop, and has nearly 3 miles of workings on the vein, which is from 1½ to 6 ft. in thickness. The ore occurs irregularly in shoots, and consists of pyrite, chalcopyrite, bornite and much chalcocite. The gangue is quartz with some rhodochrosite. The ores average 7% copper, and contain an appreciable amount of gold and silver. Chumbicha, the nearest railway station, is 100 miles from the mines. The company—the Capillitas Consolidated Mines, Ltd.—which owned the principal mines of the Capillitas and Atajo districts, appears to have suspended operations since 1907. In the Atajo district the ore deposits form a network of veins in an intrusion of porphyry or rhyolite. The chief veins are from 2 to 4 ft. in thickness, and the ores consist of quartz with auriferous chalcopyrite, tetrahedrite, pyrite and a little galena.

The Hoyada district is highly argentiferous, copper ores occurring only in subordinate quantity.

La Rioja.—In the province of La Rioja the Famatina region is of importance. The geology of the Sierra de Famatina is very complex. The principal formation is a highly metamorphosed Palæozoic slate with intercalated limestone. Other rocks are tuffs, sandstone, conglomerate, both ancient and recent, and carbonaceous schist. Among the eruptive rocks are granite, porphyry, pegmatite, dacite, diorite and greenstone.

In Los Bayos district (altitude 12,000 ft.) there is a mass of dacite with several eruptions of porphyry. No doubt the numerous fissures were formed during the cooling of the eruptive rock and were enlarged either by the kaolinization of the rock or by subsequent movements that took place in the country. One vein strikes N. 22° W. to S. 22° E. and is formed of various ore-bodies, very irregularly distributed. The ore is tetrahedrite and enargite, with pyrite showing in the lower levels. Probably chalcopyrite will be found in depth. The gangue is quartz and some barytes. The ore occurs as inclusions in the gangue, or as small concretionary masses, either alone or alternating with veinstone [184].

One ore-body has been proved to be 500 ft. long, and up to 15 ft. in width, and to contain from 2·5 to 3% copper and

8 oz. of silver per ton. The deposit is worked by the Compañía Minera Los Bayos, the production being 1,812 tons of ore in 1918. By means of a wet concentration plant only a 50% extraction is averaged; the low result may be partly due to the gangue containing barytes, so a change to flotation treatment may be beneficial [185/p. 211].

In El Ofir district (altitude 13,600 ft.) there is a contact zone of slate with a granitic and porphyritic mass, the latter being separated from the granite of the higher ranges by a band of red sandstone and conglomerate (probably Rhætic). The veins course E.-W., dip N. 50° to 60° and consist of quartz with pyrite, chalcopyrite, and some gold and silver. The copper content never exceeds 8%, and is usually much below it. Little work is being done in this section.

In La Mejicana district (altitude 14,630 ft.), the formation is slate, with varied strike and dip. At the surface the ores are very complex, with silver enrichment. Chalcopyrite is the predominant ore in depth, mixed in places with enargite, famatinite, tetrahedrite and umangite (a selenide of copper and silver), and associated with pyrite, galena, blende, etc. The matrix is quartz with some calcite and barytes. Analyses of ore from the Upulongos and San Pedro mines show 3·75 and 11·85% copper, 12 and 6 dwt. gold, and 11 and 3 oz. silver per ton, respectively. The San Pedro deposit, which is 12 to 27 in. thick, has an ore shoot 600 ft. in length, but the deposit shows continuous impoverishment in depth. The Upulongos deposit is from 24 to 43 in. in thickness, and is formed principally of pyrite. It has an ore shoot 1,200 ft. in length. At Level No. 2 the ore averages 2·9% copper, 9 dwt. gold and 13 oz. silver per ton, and at Level No. 5 it contains the same amount of copper, 4 dwt. gold and 6 oz. silver per ton. The pyrite is rich when finely divided, but when well crystallized is poor in copper, gold and silver [184].

The Famatina Co., Ltd., owns the 6 principal mines of the district, or the groups of Upulongos, Mellizas, Compañía, and San Pedro. Transport is effected by a 21½ mile ropeway built under Government subsidy. The difference in altitude between the terminals is 11,526 ft. The capacity of the ropeway is 400 tons in 10 hours. From 1910 to 1912 the mines

yielded 56,000 tons of ore, which averaged 8 dwt. gold, 6 oz. silver and 3% copper [12/p. 59]. The company's ore reserves are about 120,000 tons of average content, 4% copper, 8 oz. silver, and from 4 to 9 dwt. gold per ton.

Mining operations of the Famatina Co. have been suspended for some time, although the mines are regarded as good [10/p. 1763].

It is interesting to note that before the company erected its smelting plant, over 20 years ago, the ores used to be treated at a small private smelter at Corrales, by Fouert, an unknown, but very progressive metallurgist, who with only a wild mountain bush, named *jarilla*, as fuel, and, with a home-made producer and regenerative stove, made producer gas and succeeded in smelting the ore in a small reverberatory with it. The Famatina Co. imported its coke fuel from England [185/p. 216]. There was a small production from dump ore in 1920.

In La Encrucijada district (altitude 9,840 ft.) the formation is Palæozoic slate, the district showing much less regional and local metamorphism than others of the same range. There is a copper-bearing vein of considerable extent, and, parallel with it, is a band of green magnesian rock with inclusions of pyrite. The ore is chalcopyrite with secondary bornite, chalcocite and covellite. The gangue is argillaceous and the ores carry silver. A 20-ton smelter is or was in operation in the district.

In the Santa Rosa district (altitude 10,170 ft.) the country is slate with porphyritic intrusions. The chief mines are owned by the Rio Amarillo Copper Mining Co. A 30-ton smelter is erected at Totoral. There are 3 veins. The ore is chalcopyrite, either as impregnations in the slate, or as a true vein with a quartzose matrix. The grade rarely exceeds 10%, but is usually much below this.

In La Pararrayo district the formation is slate with numerous intrusions of diorite. The veins strike N.–S. and dip W. Chalcopyrite and chalcocite occur below the surface in an argillaceous gangue. The mineralization is very irregular [184].

The district of Valle Hermoso lies between the Main Cordillera and the pre-Cordillera (altitude, 10,990 ft.). At Las Choicas,

the deposits occur in the lower limestone (Upper Jurassic) cut by dykes of andesite. The ore is chalcopyrite, bornite and chalcocite in a matrix of barytes and calcite. Bornite and calcite are more abundant in the lower than in the upper levels. The ore carries 7 to 8% copper, and a little gold and silver. At Burrero, the deposits consist of stockworks of narrow veins in olivine-basalt, rarely over 6 ft. in thickness. The ore is chalcocite, in a gangue of quartz, prehnite, scolecite and calcite (rare), and contains no gold or silver. Native copper occurs in cavities in the olivine-basalt, and loose boulders of the native metal with prehnite gangue have been found weighing several pounds.

Córdoba.—In the province of Córdoba copper ore deposits are principally confined to two parallel zones on the eastern slopes of the Sierra Chica and Sierra Alta, but they do not appear to be of any great economic value. The Sierra de Córdoba is mainly of Archæan age, and consists of crystalline schists, gneiss, mica-schist, and phyllites, with intercalations of granular limestones (marbles), and dioritic rocks. The deposits follow the strike of the crystalline schists, being found in hornblende-schist and dioritic rocks, intercalated in gneiss. Some of the deposits have been produced by contact metamorphism caused by granite, e.g. the Cuchicorral deposit, where hornblende-schist has been altered into epidote at the contact zone, and, a little north of Tio, where a vein of pegmatite has metamorphosed hornblende-schist into epidote and garnet, which contain a small quantity of native copper, chalcocite and chalcopyrite.

Regional metamorphism has produced the same effect; for instance, granular limestone of the Córdoba Sierra, in contact with hornblende-schist, intercalated with gneiss, contains, at the contact zone, epidote, garnet and wollastonite, vesuvianite, actinolite, and, frequently, chalcopyrite, pyrite, titaniferous magnetite and ilmenite, without granite being in evidence. True veins of copper-bearing quartz, with chalcopyrite, bornite and chalcocite, occur in the Sierra; but such veins usually contain galena and blende as well, minerals which are completely wanting in the metamorphic deposits alluded to above [186].

Owing to the existing conditions, only rich ores are worked in Argentina. About two-thirds of the gold production of the country comes from copper ores.

Bolivia

The Andes traverse Bolivia in two distinct chains as the Cordillera Real, or Eastern Range, and the Cordillera Occidental, or Western Range. Between them is the Altiplanicie or high plateau. The Western Range is mainly in Peru, its eastern slope being practically the western boundary of Bolivia.

Nearly all the copper produced comes from the Corocoro district in the department of La Paz, where there are deposits of very friable red sandstone containing principally native copper, but also chalcocite and enargite. The copper is in the interstices of the sandstone, which is so friable that it easily disintegrates between the fingers. The belt of the deposits extends from the north of Corocoro through Turco and Cobrizos to the S.W. of San Bartolo in Chile. Corocoro and Lake Superior are the only places in the world where native copper is the principal mineral mined.

All the mines are controlled by two companies, the Corocoro United Copper Mines, Ltd., an Anglo-French company, and the Cia. Corocoro de Bolivia, a Chilean company.

Recently the engineers of an American syndicate examined the principal mines in the district for purchase, but did not exercise their option. Since then a wide zone of sulphide ore has been discovered, and heavy shipments have been made from it.

The copper content of the original ore containing the native metal varies from 4 to 5%. By wet concentration in jigs, after Chilean mill grinding, 85% concentrate is produced. The tailing carries from 0·3 to 0·4% copper, and the extraction is about 90%. The concentrate, called *barilla*, is exported to England. This procedure is cheaper than smelting locally, on account of the scarcity of fuel: also the export duty on the copper content of concentrate is only 70% of that on metallic copper. The smelting of the concentrate produces a copper so pure that electrolytic refining is unnecessary.

Both the Corocoro companies have been lately using the flotation process on sulphide ores. The Cia. Corocoro is just finishing a 1,000 ton concentrating mill for native copper ores that is likely to be the smallest mill in the world for its capacity. This will be owing to the extreme friability of the sandstone. An opinion has been hazarded that a ½% ore at Corocoro would be more profitable to treat than a 3% ore at Lake Superior, taking all the different conditions into consideration. Since the advent of the railway, a few years ago, both sulphide and oxidized ores have been hand-sorted to contain between 18 and 20% copper, and then shipped away [187 [188].

A not inconsiderable amount of copper is obtained as a by-product in Bolivia from the mineral tetrahedrite, which is associated with sulphides of iron, copper, lead and zinc in a barytes-quartz veinstone [45/p. 167].

From 1910 to 1914, inclusive, the copper production of Bolivia averaged 3,752 tons per annum. In 1915 and 1916 it was 5,839 and 5,151 metric tons, respectively [55/1918, p. 892]. No official figures have been issued since 1916, but the outputs of 1919 and 1920 were about 6,900 and 9,900 tons. The production of the Cia. Corocoro for 12 months ended June 1920 was 6,550 tons of copper, in the form of ore and concentrate [55/1920, p. 168].

Brazil

Very little information is available about copper mining in Brazil. In two districts only is it worthy of note. In the Rio Grande do Sul district there are deposits near Camaquam River, 50 miles north of Rio Negro station, consisting of 4 veins in schists and conglomerates, which have been intruded by basalt and gabbro, the ore being chalcocite in the upper levels, bornite, chalcopyrite and pyrite in the lower levels. The ore is picked to a 30% content, and the remainder is milled and concentrated to a 28% product. The picked ore and concentrate, which contain some gold, are shipped to England. At Cerro Martin, 86 miles north of Rio Negro station, ore carrying from 7 to 25% copper is found in fine conglomerates, associated with basalt intrusions. The Primavera mine near

Caçapava contains 7% ore; there are also copper deposits at Cerro de Geraldo, also near Caçapava.

In the Bahia district, 25 miles west of Angico, are the Minas de Cobre de Carahyba, which contain 3% oxidized ore. Mine workings are not deeper than 90 ft. and sulphide ore has not yet been found [12/p. 192].

CHILE

Chile has always been an important producer of copper. The Spaniards revived the industry in 1601, and it was carried on for a period of about 250 years, high-grade carbonate and oxide deposits being worked, and the ore smelted in charcoal furnaces. As already mentioned on page 2, Lambert built the first reverberatory furnace, and, later, the first blast furnace. Production of copper gradually increased, reaching a maximum in 1876, after which there was a decline until 1890, owing to the exhaustion of rich surface deposits and other causes. The introduction of improved mining and metallurgical methods, and the working on a larger scale than before, of low-grade deposits, during the present century, have made Chile a big producing country, and, in 1920, the second largest producer in the world with a production of 94,531 metric tons.

From early in the seventeenth century, when copper mining first commenced in Chile, to the end of 1902, the production of copper amounted to 1,983,853 metric tons [189].

The copper deposits of Chile occur mainly in a belt parallel to the coast, on a coastal range, and in a second belt inland at the foothills or on the crests of the high Andes, at a distance of 50 to 75 miles from the coast.

The rocks containing the deposits are mainly quartz-porphyries, diorites and andesites, but also basic rocks, such as dolerite, gabbro and peridotites. The primary minerals met with are chalcopyrite, enargite and bornite; the secondary sulphide minerals are chalcocite, bornite and chalcopyrite, and the oxidized minerals are brochantite, atacamite, chalcanthite, kröhnkite, malachite, azurite, chrysocolla, cuprite and native copper.

With the exception of a few mines at a high altitude, such as the Braden Company's mines, most of the mines are in

region of light rainfall or of extreme aridity, with an atmospheric temperature from moderate to high.

Due to the aridity of some regions, such as the Atacama desert, there is a large amount of the soluble or semi-soluble salts of copper, viz. brochantite, atacamite, chalcanthite and kröhnkite: in such desert regions the depth of the oxidized zone is very great.

In few cases in Chile have the primary ores been mined, so that they are usually unknown. At the Braden Co.'s mines, however, primary ore is mined, and it appears to have been reached in one or two other mines in Chile.

The secondary (sulphide) ores extend probably to a great depth, especially in Northern Chile. This promises long existence, even if the primary ores are not touched.

Tacna.—In the extreme northern province of Tacna are several small unimportant mines, but some at Putrez, Cochelimpo, Victor and Tacna are promising.

Tarapacá.—In the province of Tarapacá, which is well mineralized, mining has only been carried on in the S.E., at Collahuasi and at Quebrada Blanca.

The principal veins of Collahuasi (altitude nearly 15,000 ft.) belong to three systems: (1) Veins with a N. and S. strike, and a steep easterly or westerly dip; the filling consists of ferruginous quartz; (2) veins coursing N.W. S.E.; the filling is more argillaceous and less compact, and the ore more oxidized than (1), e.g. Poderosa veins; (3) east and west veins, carrying abundant iron and manganese in a quartz gangue, and more recent than (1) and (2) [190].

The Poderosa lode has a general strike of N. 40° W.; the dip is S.W. 40° to 70°, and the width varies from 3 to 30 ft., the average being about 4 ft. The country is stratified porphyry (the layers being parallel to a quartz-diorite dyke to the S.W.). The country has also been described as a dacite. The lode itself is a system of parallel veins or leaders (*guías*). The ores occur as lenses, parallel to the dip of the formation from 3 to 20 ft. in width. The hanging-wall consists of bluish quartzite, apparently the result of local metamorphism. From the first to the fourth levels, the predominating ores were chrysocolla,

brochantite, cuprite, and tetrahedrite; sometimes with malachite, azurite and much chalcocite. In the 4th level, bornite is abundant, and continues to be so to the 6th level, accompanied by chalcocite, tetrahedrite (usually rich in silver), and a little chalcopyrite, with diminishing chrysocolla and brochantite. The adjacent Rosario mine has been worked 80 ft. below the 6th level of Poderosa, and the prevailing ores at that depth are chalcopyrite, chalcocite, bornite, pyrite and arsenopyrite. The above mines are worked by the Compañía Minera Poderosa de Collahuasi. The Poderosa mine is between 700 and 800 ft. in depth [191].

The Quebrada Blanca group is situated 5½ miles west of Mt. Collahuasi. Here a conglomerate, composed of pebbles of quartzite, porphyry and porphyrite, cemented by clay, and from 3 to 10 ft. thick, is impregnated with native copper, cuprite, carbonates, sub-sulphates, silicates, arsenates, sulphides and suboxides of copper of varied grade. Brochantite is found with the pebbles, and the argillaceous cement contains silicate and oxide of copper. The average ore of one mine yielded 4·3% of copper. The Eudoro group of veins is in porphyry, and the main lode, which strikes N.W.–S.E., is crossed by two N.-S. veins, and has all the characteristics of Poderosa. The thickness varies from 3 to 100 ft. and the oxidized ores contain 33·7% copper [190].

The copper-bearing conglomerate of Huiquintipa is considered of greater economic value than the conglomerate described above. It consists of a breccia of porphyry in a cement of white clay. At a depth of 33 ft. from the surface, the clay cement for an equal thickness is replaced by silicate of copper. The deposit is said to be of glacial origin. Numerous analyses show the average content to be 3½% copper. The reserves of this grade are computed to be 12,000,000 tons. Water is scarce in the region [192].

Antofagasta.—The province of Antofagasta is at present the largest producer of copper in Chile, as it contains the famous Chuquicamata mines of the Chile Copper Co., which are in the Department of El Loa. The mines are 14 miles N.E. of Calama, on the Antofagasta and Bolivia Railway, at an elevation of 9,890 ft., and cover an area 2½ by ½ mile. The

region is all but rainless. The company owns 159 acres, which is almost the whole area covered by the deposits. Churn drilling has disclosed 700,000,000 tons of known and probable ore containing 2·12% copper: the known ore is about one-half of the total [12/p. 243].

There are two kinds of deposits at Chuquicamata—veins or lodes, and the *llamperas* (described below). The country may be described as a quartzose monzonite. It is crossed by numerous fracture-zones or lodes, as well as by dykes and outcrops of quartz and felsite.

The lodes have a varied strike and a nearly vertical dip. The richest deposits occur at the junctions, both on the strike and on the dip. In depth the lodes become thin and the junctions decrease. Cross-veins, when nearly vertical, have an adverse effect on the lodes, but, when more or less flat, affect them beneficially. The average thickness of the lodes is 5 ft., but at the junctions or other special points the thickness may be 30 ft. or more. Various oxidized and sulphide ores of copper are found in the lodes, the third or mixed zone having a wide range, but consisting principally of chalcocite and brochantite. The usual gangue consists of highly kaolinized country. Pyrite is abundant at 300 ft. in depth, and occurs in fine grains, or as compact masses containing 3% copper. The average ore from the lodes contains 15 to 16% copper.

Of far greater economic importance than the lodes are the low-grade deposits known as llamperas, which may be described as irregular masses of brecciated country, impregnated mainly with brochantite and atacamite. These ores in a fine state of division (*llampos*) fill the crevices of the rock. Typical aplite often appears in the llampera formation as a breccia, with fragments in regular position and cemented by copper ores or by clay (felspar) [193].

Pope Yeatman [194] has described the geology of the deposits and the gigantic operations of the company. He divides the deposits into five zones: (1) A *leached zone*, practically without copper, up to 545 ft. thick; (2) a *brochantite zone*, containing this mineral in abundance and a large number of other minerals; (3) A *mixed oxidized and sulphide zone*, with no decided demarcation between the two classes of ore, containing

chalcocite and brochantite; (4) a *secondarily-enriched zone*, containing mainly chalcocite and covellite; and (5) a *deep zone of primary ore*, containing pyrite, chalcopyrite, enargite and bornite.

The ore is leached with sulphuric acid, the solutions being precipitated electrolytically. The solution contains soluble cupric chloride, from the mineral atacamite, which is separated by precipitation with copper previously to electrolysis as insoluble cuprous chloride. This is filtered off and smelted separately. The ultimate output will be 40,000 tons a day. Only oxidized ores at present are treated (*see* [14]).

The Chile Copper Co., absorbed by the Anaconda Copper Mining Co. at the end of 1992, commenced operations in 1912; its recent outputs of copper were:

	1916.	1917.	1918.	1919.	1920.	1921.
Metric tons .	18,741	40,095	46,341	34,808	50,408	24,505

The costs of copper per pound produced and delivered in the United States were:

	1916.	1917.	1918.	1919.
U.S. cents .	15·335	19·92	17·86	23·99

The annual reports of the company contain much information [195].

There are other mines in the department of El Loa, at Conchi and at San Pedro. The deposits at the former are similar to those at Corocoro, Bolivia, and contain native copper impregnating sandstone. The San Bartolo mine, in San Pedro, has 5 ore-bearing strata containing 8% ore.

In the department of Tocopilla the vein of the Toldo mine, in the Gatico district, is from 3 to 5 ft. in thickness in syenite. The principal ores are brochantite and chalcopyrite. The mine is about 1,400 ft. in depth. The oxidized zone extends to a depth of 490 ft. At Michilla, at a depth of 60 to 100 ft., large deposits of oxides occur in porphyritic rock, 200 or more ft. in width. In 1908 the reserves were estimated at 100,000 tons of ore with 5 to 6% copper. At a depth of 160 ft. chalcocite and bornite begin to appear, which indicates a transition to sulphides (*bronces*).

In the department of Antofagasta the San Bartolo mine as five sandstone beds containing native copper.

In the department of Taltal, the rich gold-bearing veins of ıe Guanaco district have been found to change to copper in epth.

Atacama.—The province of Atacama contains hundreds of copper deposits. The ores have to be hauled great distances, so transport costs are high and only the richest ores can be taken away. Occasionally ores containing up to 15% copper are left behind. The Exploradora mine in the department of Chañaral in 1913 shipped 13% ore, leaving 75,000 tons of 7 and 8% ore on the dumps. It has to haul its ores 125 miles. Mines at Salado, Pueblo Hundido, Las Animas and Los Pozos, near the railway, send away 7% ore. In the Los Pozos district is the Manto Monstruo ore-body, over 300 ft. thick : its gossan, where prospected, contains from 4 to 7% copper.

The French Société des Mines et Usines de Cuivre de Chañaral owns various mines in the district of Los Pozos. The deposit of Las Animas consists of veins in syenite (? diorite) which have been worked to a depth of 1,800 ft. The oxidized ores extend to about 50 ft. in depth. The sulphide ores consist mainly of chalcopyrite. The ore sent to the smelter averages 4 to 5% copper. Los Pozos consists of two parallel ore-bodies in porphyry (? porphyrite) and syenite. The width has not been determined, but the workings show large deposits of the porphyry type. The ore averages 6% copper. The smelter, consisting of four blast furnaces, is at the harbour of Chañaral [10/p. 1778]. The estimated ore reserves are 10,000,000 tons. Research work is being carried out in France, England and the United States to discover the best method of treating the oxidized ores which have been left in the mine [196].

In the centre of the department of Chañaral is the famous deposit of the Potrerillos mine, which is being opened up by the Andes Copper Mining Co., a subsidiary of the Anaconda Copper Mining Co. The mine is 90 miles inland, at an altitude of 10,500 ft. The deposit is 1,800 ft. long, 900 ft. wide and 850 ft. deep. It has been described by J. E. Harding [197], and is a late intrusion of quartz-porphyry in limestone. The reserves at the end of 1918 amounted to nearly 110,000,000

tons of 1·5% ore. A 15,000-ton concentrating plant has been built on the mine and a 22,000 kw. steam turbine plant has been erected at the port in Barquito Bay. It is estimated that £5,000,000 will have been spent before any copper is produced.

In the department of Copiapó, mines have been worked a long time, as the Caldera Railway, the first in South America, was built in 1852. The Copiapó region contains a north and south copper-bearing belt, east of the city of Copiapó. The Dulcinea mine, 7½ miles west of Puquios, the deepest in Chile, has been worked to a depth of about 3,600 ft. The oxidized zone is in places 1,700 ft. deep and much 30% oxide ore has been taken from the first 600 ft. The chalcopyrite and pyrite ore now carries 8% copper with 4 oz. silver per ton. Many abandoned mines in Copiapó will probably be reopened.

In the department of Freirina, near Carrizal Alto, are many mines, mostly idle, some over 1,000 ft. deep. The Socavón mine, 15 miles from Peña Blanca, contains a 6 ft. vein with 18% copper in granite.

Coquimbo.—There are hundreds of mines in the province of Coquimbo, worked alongside the Longitudinal Railway line, the largest producers being those at La Higuera. A large number of mines are worked in the Compañia district; the Brillador, worked to a depth of 1,650 ft., has been a noteworthy producer.

The Chile Central Copper Co., Ltd., owns mines at Panulcillo and at Nisñile, the former including the Panulcillo Alto and the San Gregorio. It also owns a 400-ton smelter and treats its own and custom ores, producing about 2,500 tons of copper per year. Its matte is refined in New York.

Aconcagua.—In the province of Aconcagua the mine of Los Mantos in the department of Putaendo is the most important one and is worked by the French Société des Mines de Cuivre de Catémou. The mountain of Los Mantos is formed of stratified metamorphic porphyries on which rest sedimentary beds of sandstones and limestones. There are two deposits of the bedded vein or blanket (*mantos*) type occurring in limestone cut by eruptive dykes. The principal ore is bornite; some tetrahedrite and chalcopyrite also occur. Galena and blende are present in small quantities. The zone of oxidation does

not exist, having been removed by erosion. The average ore contains 4·5% copper, 1% lead and 2% zinc, and 1 oz. silver per ton. In 1918 this mine produced 5,000 tons of ore per month, averaging 4% copper. The French company owns several other mines in the province. The veins of El Soldado have a N.-S. strike, and lie on a fault contact between trachyte and felspar porphyry. These ores average 10% copper. There are two smelters, 11 miles apart; one is at La Poza, at the foot of the mountain, and the other is at Chagres, near Chagres station, on the Transandine Railway. In 1907 the production was 1,509 long tons; in 1918 it reached 4,063 tons. Water is scarce, but there are two concentrating plants employing flotation [198] [10/p. 1776].

The deposit known as Cristóbal Colon is nearly at the summit of the mountain chain forming the left side of the Rio Blanco valley, and 3 miles from a station on the Transandine Railway. A narrow vein of high-grade copper ore with high silver content crosses three thick beds of mineralized volcanic tuff. The beds, having a total thickness of 50 ft., contain, on an average, about 5% copper and some silver. The ore is smelted direct in a cylindrical furnace at Chagres, which has been improved by Ignacio Diaz Ossa. The daily capacity of the furnace is 20 tons. About 25% of the copper is obtained in bars of 90% metal—the other final product being matte containing 75% copper [199].

Santiago.—In the department of Melipilla, province of Santiago, the French Société des Mines de Cuivre de Naltagua owns various mines and a smelter. The deposits consist of sedimentary beds (*mantos*), impregnated with copper ores, and traceable for 3 miles. San Ramón, the principal deposit, has a bed of black calcareous schist of Mesozoic age, broken up by faults filled with clay, up to 3 ft. thick, which produce vertical throws of 10 ft. or more. Here and there horses of rock interrupt the continuity of the bed. The strike is N.-S. and the dip E. 30°. The average thickness is about 5 ft. and the copper content is about 4%. Oxides occur to a vertical depth of 65 ft.; below this depth the bed carries bornite for a further vertical depth of 65 ft., when chalcopyrite begins to appear. The copper ores are found in very fine stringers (*guías*), very

evenly distributed in the black schist. Metamorphic porphyries of the Andine formations crop out here and there. In 1909 the workings were 2,000 ft. in length and 160 ft. in depth. The company's smelter consists of two blast furnaces with converters, the capacity being 350 tons of charge per 24 hours. In 1918 two 17 ft. by 55 ft. reverberatory furnaces of the Anaconda type, fired by pulverized coal, were in full operation [203].

The Santiago Mining Co., a subsidiary of the Anaconda Copper Mining Co., owns several groups of mines, which are 12 miles west of the city of Santiago in the same department. In Lo Aguirre mine, the ore occurs as a disseminated deposit. Work, begun in 1914, has developed more than 6,000,000 tons of ore carrying 1·75 to 3·5% copper. The ore is a mixture of oxide and sulphide. In the Africana mine the ore occurs in veins, and contains from 4½ to 9% of copper. The excess of sulphur in the ore will be converted into sulphuric acid for leaching the oxidized ores of Lo Aguirre [10/p. 1786].

Los Bronces district is in Las Condes range of mountains in the department of Santiago, and is at an altitude of 11,800 ft. The formation consists of porphyritic breccia surrounded by subsidiary masses of dioritic rock—having a system of N.E. fissures. The deposits consist of large irregular masses of chalcopyrite in relation to the fissures, sometimes many cubic metres in volume. From October, 1908, to April, 1909, the output was 6,000 tons of chalcopyrite, carrying more than 20% copper. The smelter, which is 18½ miles from the mine and at an altitude of 8,700 ft., consists of three circular masonry, water-cooled, blast furnaces, 13 ft. in height and 5 ft. in diameter, the capacity of each being 30 tons of charge per 24 hours. There are three converters of the ordinary type. By using electro-thermal reduction the capacity could easily be doubled, and the cost of treatment reduced by nearly a half [200]. At Las Condes mine chalcopyrite occurs as the cementing material of a volcanic breccia, which is estimated to contain 3 to 4% copper. The deposit is very extensive and has been compared with the Braden deposits (farther south). Copper sulphate deposits occur in the same district [12/p. 260].

O'Higgins.—The Braden copper mine lies east of Rancagua at an altitude of 8,000 ft., and belongs to the type of deposit which carries quartz, tourmaline, pyrite and chalcopyrite. The geological history, according to Lindgren and Bastin, [201] is complex, comprising three periods of igneous intrusion, three periods of mineralization by ascending solutions, uplift and tilting of the land, erosion of the surface and chalcocite enrichment of the ores by waters descending from the surface, etc. The second or main period of primary mineralization followed a volcanic vent caused by an explosive eruption of molten and partly molten rock leaving a shattered zone in its periphery.

At the end of 1918 the ore reserves were 177,000,000 tons of positive ore of 2·45% grade and 88,000,000 tons of probable ore of 1·88% grade.

The mines are connected with the company's treatment plant by a railway 5,750 ft. long, graded at 1 in 200, of which 5,000 ft. is underground to avoid snow slides. The plant consists of a smelter at Sewell, of capacity 350 tons of concentrate a day. The concentrate is produced by a wet concentration and flotation plant, the capacity of which is being brought up to 10,000 tons of ore a day. At this rate of treatment the known ore reserves would last about 35 years. The 1919 and 1920 outputs of copper were 23,500 and 32,459 short tons.

Magellan.—Copper deposits have been discovered in the Territory of Magellan, extending to the neighbourhood of Cape Horn (lat. 56° S.). At Cutter Cove veins occur from 13 to 19 ft. thick in diorite and syenite country. The filling is quartz and chalcopyrite, with an average content of 6% copper [202].

The following are recent productions of copper in Chile:

	1915.	1916.	1917.	1918.	1919.	1920.	1921.*
Metric tons .	52,341	71,288	102,527	106,814	70,000	94,531	55,721

* Formerly much of the output went to England and to

France, as is shown by the following table of productions for 1912 and 1913:

	1912.	1913.
	lb.	lb.
Blister copper to U.S.A.	8,627,421	18,315,000
Copper in ore to U.S.A.	27,445,679	24,911,465
Copper to England and France	50,136,800	43,460,480
Sundries estimated	220,000	250,000
Total lb.	86,429,900	86,936,945
Total metric tons	39,204	39,434

Recently all copper has been sent to the United States [203].

Production of copper in Chile is increasing at a great rate and the large American companies expect to be producing several hundred thousand tons of copper per year before long. Future increased production is likely to come from large low-grade disseminated deposits and from rich vein mines, which will be reopened [12/p. 233]. The copper industry would be stimulated by the building of more railways, although in this respect Chile is well ahead of other South American countries.

Colombia

Although Colombia contains high mountainous country, with elevations up to 20,000 ft., few important discoveries of copper have been made.

At Natagaima, in the department of Tolima, are ore deposits as nests, veinlets or impregnations of dolerites and olivine-basalt or metamorphosed sedimentaries, containing chalcocite with chalcopyrite. At Moniquirá, in the department of Boyacá, are ore deposits in sandstones. There are other deposits at Cundinamarca, at Antioquia, at Chocó and at Nariño. On the west slopes of the Cordillera Occidental, near Rio Tigurido, are copper veins from 1 to 13 ft. wide, containing 25 to 32% copper, with 2 to 2½ dwt. gold per ton [12/p. 355].

The copper production of Colombia is insignificant.

Ecuador

No copper deposits have yet been discovered in Ecuador, but the silver ores of Pillzhum have a high copper content.

Paraguay

The only known occurrence of copper in Paraguay is in a basalt dyke near Encarnación, where it exists as malachite and azurite.

Peru

Geographically Peru consists of three portions: the Coastal Region on the west, a narrow strip, flat, and mostly desert country; the Montaña, or eastern portion, on the eastern slopes of the Andean Range, containing a portion of the basin of the Amazon and tributaries; and a Central or Andean Belt, of high elevation, running north and south, and mainly about 150 miles wide. The last is separated, for a great portion of its length, from the Coastal Region, by the Western Andean Range; from the Montaña, by the Eastern Range, and it is itself divided for a portion of its length into a western and an eastern division by a Central Range.

The most highly mineralized area is in the Western Andean portion, a strip about 75 miles wide, and in this the mineralization is more intense in the north than in the south. The rocks are mainly Mesozoic sediments and porphyries of Tertiary age.

Farther south Palæozoic rocks become the principal country rock of deposits. The ore deposits are mainly of silver, silver-copper and silver-lead, and it is difficult to distinguish one from another.

The greatest mining developments have taken place in the departments of Cajamarca, Libertad, Ancachs, Junín, East Lima, and North-East Huancavelica.

Cajamarca.—In the department of Cajamarca, the Tingo copper region lies in the Hualgávoc district, in the province of the same name. The altitude is about 12,000 ft. Sedimentary limestone of Cretaceous age is succeeded by diorite. The veins or masses follow the contact zone. The country

has frequently undergone silicification, and the minerals have been deposited by ascending solutions. The characteristic ore is enargite, which is regarded as primary, and is associated with chalcopyrite and pyrite, together with some tetrahedrite (with 30 to 650 oz. silver per ton), galena and blende. The secondary minerals are malachite, azurite, cuprite, earthy oxides of iron and bornite (rare). The gangue is silica, replacing the country, or appearing as milky-white quartz containing bundles of long prisms of enargite enclosed in its mass.

These deposits, containing enargite, are comparable with those containing the same mineral in Morococha (department of Junín), and, according to E. J. Dueñas, the enargite type of copper deposit is always connected genetically with andesitic magmas of very varied composition [204].

Copper ores, associated more or less with silver ores, are also found in the provinces of Celendín, Cajamarca, Contumazá and Cajabamba.

Libertad.—In the department of Libertad the veins of the Carangas district are enclosed in shales and sandstones which have been metamorphosed by granite. The Santa Catalina vein, 3 ft. in thickness, contains tetrahedrite, chalcopyrite, pyrite and quartz with banded structure. There is about 1% copper to every 30 oz. of silver in the ore—the actual silver content being from 50 oz. upward.

At Quiruvilca, in the province of Santiago de Chuco, the country is andesite, which is crossed by numerous fractures. The filling consists of enargite, tennantite and tetrahedrite—characteristic ores of nearly all the veins—bornite, pyrite, marcasite, galena, blende, quartz, calcite, barytes and kaolin (from the decomposition of the andesite walls). Some veins contain traces of platinum, and nearly all carry gold and silver. The lodes may be regarded as copper-bearing, the silver content being under 30 oz., the gold not exceeding 6 dwt. per ton and the copper varying from 8½ to 39%. The veins of Llacapuquio, however, are an exception as they are rich in silver, and contain only 4 to 5% copper [205].

Copper is also found in the districts of El Toro and Serpaquino, in the province of Huamachuco.

Ancachs.—In the department of Ancachs, Recuay is the most important district of the province of Huaraz. The principal vein is the Collaracra, which is enclosed in a porphyry dyke, and which carries 3 to 7% copper and about 75 oz. silver per ton.

In the Huinac district, of the same province, at an altitude of 14,300 ft., are veins carrying 3 to 7% copper and 30 to 60 oz. silver per ton. The Magistral or Conchucos district of the province of Pallasca, at one time an important silver producer, now yields copper ores. The filling is pyrite and chalcopyrite, with a little tetrahedrite and bornite in a quartz and calcite gangue, and averages 12% copper. The mineralized zones are in limestone, intruded by andesite, and reach 100 ft. in width.

At Tuco, in the province of Bolognesi, are fissures in sedimentary rock carrying 15 to 35% copper and 60 oz. silver per ton. The filling consists of cupriferous pyrite, chalcopyrite, tetrahedrite and blende. In the Raura district, in the province of Cajatambo, are ores carrying from 9 to 15% copper and 70 oz. silver per ton.

Huánuco.—In the department of Huánuco, a silver-copper-lead belt traverses the province of Dos de Mayo. The ores consist of argentiferous pyrite and tetrahedrite in a quartz gangue, with chalcopyrite, galena and blende as accessory minerals. Sorted ores carry 14 to 17% copper and 500 to 680 oz. silver per ton, and milling ores 1½ to 2% copper and 50 to 70 oz. of silver per ton. In the Queropalca district are veins in quartzite containing varied copper, silver and gold contents [12/p. 454].

Junín.—The department of Junín produces about 90% of the total copper output of Peru. The copper is produced mainly at Cerro de Pasco and at Morococha.

The Cerro de Pasco was a silver-mining camp from 1630 to 1898, during which period only oxidized ores were treated. Since 1898 the copper ores below the leached oxidized zone, 300 ft. deep, have been treated, and the camp became a copper producer. The Cerro is at an altitude of 14,300 ft. and is on the pampa between the central and western ranges of the Andes. The country is limestone and limestone-conglomerate,

with which are associated some shales and sandstones. The age is probably chiefly Cretaceous. The ore deposits are found mainly in rhyolite agglomerates and tuffs.

The oxidized ores, about 100 ft. deep, are known as *pacos*, and consist almost entirely of oxidized silver ores without copper, so the deposit is a good example of the concentration of silver and the leaching of copper in the zone of oxidation.

The sulphide ores consist of a mass of pyritic material carrying silver. At the north end is a layer of rich copper ore overlying pyrite, which, at a depth, contains galena and blende. Farther south is the Piña Blanca ore shoot containing pyrite, enargite and famatinite. Rich ore, found occasionally, has the appearance of secondary sulphides within the mass of lean primary pyrite. East and west cross veins, on the west side of the sulphide stocks, are important, especially on the west of the Piña Blanca.

The chief operator on the Cerro is the Cerro de Pasco Mining Co. formed in 1902; besides, there are several small producers, of which E. F. Fernandini is the chief. The company is a subsidiary of the Cerro de Pasco Copper Corporation, which also controls the Cerro de Pasco Railway, and the Morococha Mining Co. referred to below.

The Cerro de Pasco Mining Co. controls 400 acres of mineral land, which is about three-fourths of the rich Cerro de Pasco district, a large area of miscellaneous land, a 12,000 h.p. hydro-electric power plant, a smelter at La Fundición, 9 miles away, and coal mines, from which fuel is extracted and coke is produced. This renders the company independent of imported coke. The smelter consists of 5 blast furnaces, 3 reverberatories, 14 McDougal roasters, 6 sintering machines, and 4 basic converters [206]. It will be replaced by another smelter to cost £1,800,000, which will be the largest in S. America. The blister copper of 99% content is shipped to Baltimore for refining. The 1919, 1920 and 1921 copper productions were 29,064, 31,564 and 28,147 short tons.

The Cerro de Pasco Railway, 83 miles long, joins the mine with Oroya on the Central Railway of Peru, and is also connected with the coalfield.

In the mine reserves of ore are blocked out to have 4 years'

ply on hand. This supply includes first class ore containing 8 to 10% copper with good silver content, and second ss ores of uncertain copper content. The company has so r spent £5,000,000 in opening up and equipping the property, nd this expenditure seems to be justified by the results obained.

In the Morococha district, province of Yauli, department of Junín, the Morococha Mining Co., affiliated with the Cerro de Pasco Co., owns the Gertrudis, the San Francisco, and the San Miguel mines, and one-half of the Natividad mine, the other half being owned by the Backus and Johnston Co. The properties are north of the Oroya Railway, which crosses the divide at 15,865 ft. elevation and is the highest railway in the world. The camp dates as a copper producer from 1894, when the railway was brought near. The company's ore is smelted by the Cerro de Pasco Co. The annual production is about 9,000 tons of copper with silver.

The sedimentary rocks consist of a great series of limestone and quartzites of Mesozoic age, in part, at least, Cretaceous. The two igneous rocks, which occur in connection with the ore-bodies, have been determined by C. P. Berkey to be porphyry and peridotite. The most important veins occur in the porphyry; when they reach the contact of porphyry and peridotite, if the contact is steep, they rapidly fray out, but if relatively flat, the ore-body spreads along the contact to form flats or "mantles" (*mantos*). The filling consists of quartz, pyrite, enargite and tetrahedrite. Blende is plentiful in some veins [12/p. 482].

The San Miguel mine has been worked to a depth of over 980 ft. There are ore-shoots pitching N.E. 48° and 56°, respectively. The water flowing from the adit is highly charged with copper sulphate, and copper is precipitated from it by iron. The ore is mainly enargite, with some tetrahedrite and tennantite, associated with pyrite. The mine was opened in 1893 and in 10 years produced 6,357 long tons of copper, and 348,000 oz. silver from ore averaging about 20% copper and 11 oz. silver per ton [10/p. 1795].

In the Cerro San Marcelo some silver-copper veins occur in limestone, but where the latter is metamorphosed, as at

Yanamina, it is rich in silver and without copper. In the Herminia mine there is a contact-deposit in the form of a bedded vein, which contains up to 18% copper, the floor being limestone and the roof dacite.

The Churruca deposit, situated, like the San Miguel mine, in the Cerro San Francisco, is of lenticular form, the filling consisting of a compact mass of chalcopyrite and pyrite, containing fragments of country rock—a metamorphic calcite resembling marble. Dacite occurs near the deposit. An arch or vault was probably formed here, which was subsequently enlarged by the circulation of the thermal waters from which the ore was deposited [207].

At Cachi Cachi, Jurassic or Cretaceous limestone, with sandstone or shale, is intruded by melaphyre or andesite. The mineralization, which is genetically related to the igneous rocks, consists of cuprite, malachite, native copper, pyrite, hæmatite, limonite, quartz, and calcite [12/p. 460].

In the Huaillay district, province of Cerro de Pasco, is the region known as Huancavelica (not to be confused with the department and district of the same name farther south). The region is on an anticlinal fold, trending N.N.W.–S.S.E. The centre is characterized by an immense eruptive mass of micaceous dacite, which has uplifted and highly metamorphosed the surrounding sedimentary rock. The latter is also intruded by dykes from the former. The dacite and the sedimentary aureole are crossed by numerous fractures, striking E.–W., and, as a rule, containing copper ores, enargite and tennantite, in the eruptive, and galena and blende in the sedimentary rock (marls and sandstones), although there are many exceptions to this. El Traviesa was the most important copper vein of the region in 1907. The filling is enargite, associated with bismuthinite, stibnite, tennantite and chalcopyrite in a quartz gangue. Average samples vary from 3·70 to 22·62% copper, and contain a fair proportion of silver. The ore deposits have many characters in common with those of Morococha, province of Yauli, situated 50 miles to the S.S.E. [208].

In the provinces of Jauja and Huancayo copper lodes are found in schist, limestone, sandstone and volcanic rocks

Tertiary basic eruptive has been the carrier of the copper. odes in the limestone and volcanic rocks show minerals of secondary enrichment (bornite and tetrahedrite) in a gangue of calcite, which contains druses of chalcoyprite, pyrite and, rarely, galena. Quartz is rare, and occurs filling almond-shaped cavities in the calcite. The lodes in the schist and quartzite carry pyrite and chalcopyrite in a gangue of siderite and quartz [206].

In the Atacocha region, 10 miles N.E. of Cerro de Pasco, the Parlamento mine has a vein which strikes N.-S. and is 3 ft. thick in calcareous rock. The ore is chalcopyrite, and contains 14% of copper and some silver [209].

Lima.—In the department of Lima, the Casapalca district, of the province of Huarochiri, is largely worked for its copper-silver ores. The country is andesite, intrusive in limestone. The Carlos Francisco is an old mine, which has been proved by an adit to the depth of 2,460 ft. In the Bentin mine the principal ores are galena, tetrahedrite, pyrite and blende; the gangue is quartz with a little calcite. The second or concentrating ore contains a little over 1% copper. The Backus and Johnston Co. of Peru owns a group of copper-silver mines in this district.

In the Pacococha district veins course N.E.-S.W. in altered hornblende-rhyolite. The filling is argentiferous chalcopyrite and pyrite, accompanied by some argentiferous galena and a little blende, in a quartz veinstone. The average ore contains about 8% copper, besides lead, zinc, and silver, and an appreciable amount of gold. In the Carampona district there are copper-silver-lead lodes in andesite, or at the contact of andesite with limestone. The ores are argentiferous chalcopyrite and galena in a quartz gangue [210].

At Huitor, near Yauyos, two systems of veins, having N.W. and N.E. strikes respectively, and nearly vertical dip, occur along the contact of metamorphosed shales and diorites. The ore consists of red hæmatite impregnated with malachite and chrysocolla in a matrix of quartz and calcite. The copper content varies from 12 to 15% [12/p. 460].

The Peruvian Copper and Smelting Co. has been developing its extensive holdings in the Yauyos district, and in 1920

was reported to have 400,000 tons of ore reserves with 16% copper and 3,000,000 tons of probable ore. Its 100-ton smelter is being enlarged to 300 tons capacity [55/1920, p. 173].

Huancavelica.—In the department of Huancavelica the Paucartambo district of the province of Tayacaja has veins of silver-bearing galena, with which chalcopyrite and argentiferous tetrahedrite are associated. The Casque copper deposit lies 6 miles N.E. of the town of Coris. The filling consists of copper and other sulphates, with pyrite, galena, blende and spots of tetrahedrite. In the Huaribamba district the principal country is black clay-slate. One vein courses W.N.W. to E.S.E. and is 20 ft. thick, the principal ore being a mixture of chalcopyrite and pyrite, disseminated in spots in the filling. Elsewhere a kersantite is mineralized with chalcopyrite and pyrite. Another deposit is a bedded vein in limestone, dipping N.E. 45°. The thickness is 6 ft. Tetrahedrite occurs in spots and veinlets, with some pyrite, in a gangue of calcite and some quartz. The copper ores, when pure, yield from 24 to 26% copper, and 6 to 10 oz. silver per ton.

In the Azapara region a bed of red sandstone up to 16 ft. in thickness is impregnated with bornite in small spots or nodules and threads; other minerals are calcite, quartz (rare) and chalcopyrite, the last sometimes forming the core of masses of bornite, which occasionally passes to chalcocite. Other beds in the same district are also impregnated with bornite. In the Salcabamba district are deposits in red rocks (Triassic), associated with altered granite and other intrusive rocks. The filling consists of bunches of bornite, with some chalcocite, in a gangue of calcite with some quartz; chalcopyrite, galena and pyrite are rare. In the Pampas district copper veins strike N.-S. and dip 70° in slates. Tetrahedrite sometimes forms a nucleus surrounded by chalcopyrite, or appears as little spots enclosed by siderite.

In the province of Angaraes some copper ores (chalcopyrite and tetrahedrite) are associated with argentiferous galena in the Julcani mineral region. In the Acobamba district a red sandstone and a red porphyritic rock contain hæmatite, impregnated with copper carbonate.

At Alto Bongo, in the silver-lead region of Nañantuyo and

Tapralla, province of Huancavelica, the formation consists of sandstones, red conglomerates, melaphyres and hardened clays. One deposit consists of a number of irregular little veins of bornite, principally in shale, which is impregnated with malachite. Another vein is in a red amygdaloid with two leaders containing chalcocite with some tetrahedrite and malachite. The gangue is gypsum. Another copper deposit is in limestone interstratified with a bed of melaphyre. The latter is impregnated with bornite, covellite and malachite, with some calcite, and appears to have been the carrier of the copper sulphide [211].

Ica.—In the department of Ica copper deposits are confined to the N.W. portion of a narrow band of labradorite-diorite and quartz-diorite, with patches of limestone and sandstone, which lies to the east of and runs parallel with a wide band of Tertiary and Quaternary sedimentary rocks. These two bands trend N.W. to S.E., or parallel with the Western Cordillera of the Andes. The labradorite-diorites are traversed by dykes of hornblende-andesite, as well as by numerous fractures of various ages.

The copper-bearing veins follow a band parallel to the principal fracture of the region, by which labradorite, basalts, and perhaps rhyolites, have been injected for a minimum length of 60 miles. The lodes are more recent than the rhyolite, and are probably of Pliocene or post-Pliocene age. They strike N.E. to S.W. or at right angles to the veins carrying gold and silver, and have been followed to a depth of 650 ft. The oxidized ores are represented by chrysocolla, malachite, atacamite, cuprite and native copper, with various iron oxides, and the sulphide zone by marcasite, pyrite, pyrrhotite, chalcopyrite and tetrahedrite. The secondary ore includes covellite, chalcocite, bornite and chalcopyrite. At and near the surface is an impoverished zone, below which is the zone of oxides with insoluble chlorides and carbonates. Still farther down is the transition zone, containing sulphides of both primary and secondary formation. This zone of secondary enrichment passes by insensible degrees to the primary zone of sulphides. In 1905 the reserves were estimated at 55,000 tons containing 10% copper. Scarcity of water and of labour, and high

freights have hitherto prevented the development of the region [212].

Cuzco.—In the Vilcabamba district of the department of Cuzco a group of copper-bearing veins occurs in limestone. The ores are chalcopyrite, bornite and tetrahedrite (rare), assaying 25% copper and 16 oz. silver per ton. Some ill-defined deposits of bornite and calcite occur at Checca.

Apurimac.—In the district of Ferrobamba, in the province of Cotobambas, Apurimac, at about 70 miles west of Cuzco, is the copper mine of Ferrobamba, Ltd., consisting of 165 claims. The mine is at present not in operation, mainly owing to want of capital and to lack of transport facilities, but it is reported that there are reserves of 3,000,000 tons of positive and probable ore of gross value £6,465,000 and 12,000,000 tons of possible ore of gross value £28,000,000.

Puno.—Argentiferous copper ores are being produced in the vicinity of the Maravillas smelter, west of Lake Titicaca in the department of Puno. In the province of Moquegua are various districts containing lead-copper ores.

Arequipa.—In the department of Arequipa some chalcopyrite and tetrahedrite occur with the important silver and silver-bearing ores of Caylloma. Large low-grade copper ores disseminated in rhyolite, occur at Cerro Verde, near Arequipa, the capital.

Moquegua.—In the Toquepala Valley, in the department of Moquegua, are copper-bearing veins in granite. One of them has a N.–S. strike, dips 70° and is 25 ft. thick, and consists of chrysocolla, malachite, azurite, cuprite, melaconite and ferruginous quartz: the copper content averaged 11%. The mines are now abandoned. To the N. and N.E. of Ilo are similar ores containing also copper sulphides. The ore from the San Juan mine contained 20% copper [12/p. 460].

In Peru scarcities of fuel and of labour, lack of transport, and difficulties of working at high elevations are obstacles to the development of copper-mining. There are many deposits of coal, but often in inaccessible places and of inferior quality for smelting purposes [12/p. 492].

Recent productions of copper in Peru are as follow:

	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Metric tons	34,728	43,078	45,176	44,414	39,230	31,276	33,800

The destinations of the copper productions for 1912 and 1913 are shown in the following table:

	1912.	1913.
	lb.	lb.
Blister Copper in U.S.A.	43,891,439	42,667,436
Copper in Ore to U.S.A.	11,373,009	10,089,592
Copper to England and France	2,900,000	3,180,800
Sundries estimated	220,000	250,000
Total lb.	58,384,448	56,187,828
Total metric tons	26,483	25,487

URUGUAY

Copper is found in the southern departments of Maldonado, Minas and San José, of Uruguay, where there are many gold-copper mines, most of which have been abandoned. The Oriental mine in Maldonado, 20 miles south of the town of Minas, has been idle for many years. It contains three small parallel veins of bornite, chalcopyrite and pyrite, stated to assay from 8 to 19% copper. Four miles west is a malachite vein. The Soldado gold-copper mine, 30 miles S.W. of Minas, was shut down in 1910. Its ore is in small veins, which contain in places 4 oz. gold per ton and 40% copper.

A real mining industry never existed in the country [213].

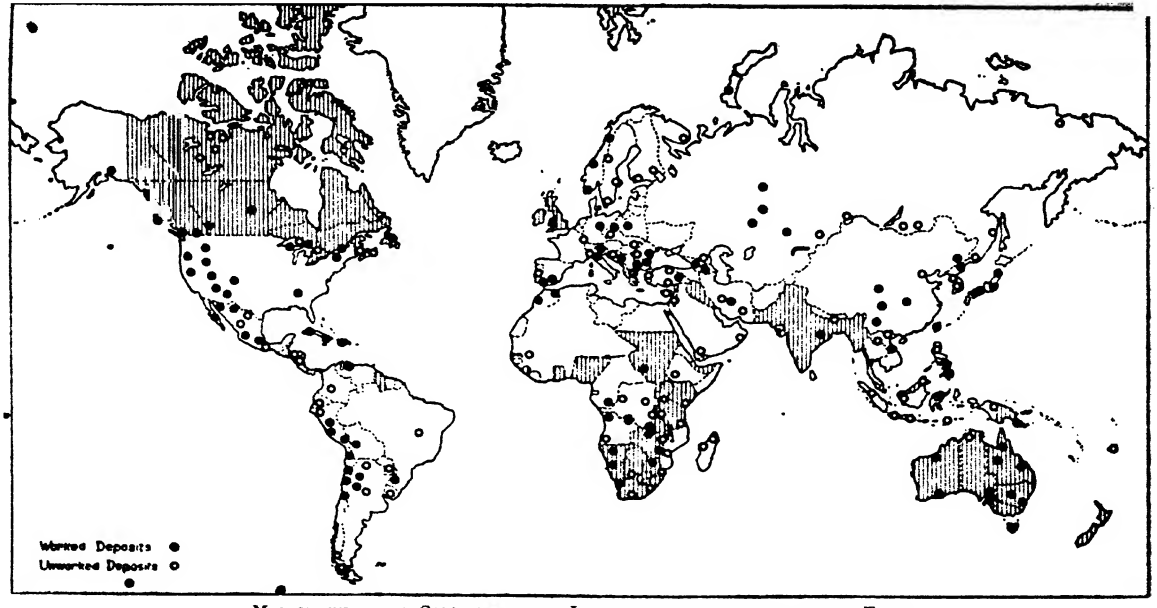
VENEZUELA

The most important copper mining district in Venezuela is about 67 miles west of Puerto Cabello, in which the South American Copper Syndicate, Ltd., is operating the Aroa mines. These date from 1605, when they were first discovered by the Spaniards. An English company operated them from 1862 to 1880, when they were closed down, after large outputs had been produced. The present company reopened the mines in 1907, and restarted smelting in 1915, making a profit in

that year of £21,489. The country rock consists of slates and limestones which are cut by dykes of igneous rocks. The ore-bodies are irregular lenticular masses within the slates and contained, in the upper levels, oxidized ores of malachite, azurite, melaconite and cuprite, and in the lower levels mostly chalcopyrite and pyrite. The oxide and low-grade ores are matted locally, whilst over 9% ores are shipped to Swansea. In 1917, 48,542 short tons of ore were mined; in 1918, 21,386 tons. Production, suspended in 1919, has since been resumed, and a 200-ton smelter has been erected. According to a recent report, owing to a new discovery of ore, the probable reserves have been placed at 600,000 tons of 5% ore.

Near the Aroa mines is La Cumaragua, a promising mine recently opened up by a local company which mined 580 tons in 1917. Only carbonate ore has been found so far.

According to Charles Caracristi the total copper production of Venezuela for 1917 was worth $1,966,760, and that for 1918, $855,440 U.S. currency. These figures were obtained from steamer invoices. The Government keeps no statistics [214].



MAP SHOWING THE COPPER-BEARING LOCALITIES REFERRED TO IN THE TEXT.
(British Empire shaded.)

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